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I. INTRODUCTION

This study aims to make a detailed and exhaustive analysis of a simple case of trial and error learning. The tracing of a six-pointed star, as reflected in a mirror, was selected as the task to be learned—for the threefold reason that this task promised to involve a certain degree of difficulty for the learner; that improvement in learning to trace this figure promised to be rapid and to be open to accurate objective measurement; and that the time required to make a single complete tracing of the figure promised to be sufficiently short (the average time proved to be less than thirty seconds), to enable the learner to furnish a subsequent introspective description of his mental processes and procedure in complete detail.

Our method of investigation involved objective records and introspective analyses; and we aimed to obtain, from both these sources, a complete description of every step in the act of learning; it was also hoped that each method would furnish a check upon the accuracy of the other method.

It has been our endeavor to submit every stage of our act of learning to detailed analysis; and then to recombine the results of these analyses and to present them in their proper sequence. By this means it was hoped to obtain a complete genetic record of the act of learning at each stage of its development.

Psychologists have attempted in recent years to determine what differences obtain between learning in animals and in the human subject. The term 'trial and error' learning has come to be employed in certain quarters to describe the learning of the animal; and in certain quarters this term has been employed to designate a certain sort of human learning.

It seems probable that the term was first employed by students of animal behavior, and that its application to human learning is of a more recent date. The earliest use of this term which we have been able to discover appears in Galton's *Inquiries*,[1] where, how-

[1] Francis Galton, Inquiries into human faculty, London, 1883, p. 171. In describing the movement of the eye over the details of the 'fire face' in the burning coals, Galton speaks of it as "being guided partly by the easy sequence

ever, one is led to suppose that the phrase was current at that time. It was soon pointed out that 'trial and success'[2] would describe this sort of learning more accurately than 'trial and error'; and in describing the learning of certain animals, Thorndike (46)[3] emphasized the significance of the 'accidental success' which attended certain reactions of his animals when placed in the learning situation. He also points out that human learning differs from animal learning in that the latter is characterized by an absence of independent ideas and by a lack of continuity in the mental stream. In a later study[4] he differentiates three sorts of learning: "Learning by trial and accidental success,—that is, by the strengthening of the connections between the sense impressions representing the situation and . . . our successful response to it, and by the inhibition of similar connections with unsuccessful responses"; learning by means of imitation; and learning by means of ideas.

Lloyd Morgan (26) employed the term 'trial and error' learning to refer to that type of behavior which obtains in the dog when he learns to meet a situation successfully. Morgan believes that the dog's reactions to a situation are immediate responses which owe their origin either to the animal's racial or his individual experience; the behavior of man, he points out, is of a wholly different sort, in that man approaches a problem deliberately, marshals his past experience, and 'reasons out the difficulty' before he acts.

In more recent years experimental investigation has shown that a fundamental distinction between human and animal learning can be drawn only with the greatest difficulty. In investigations of human learning Ruger (37) and Book (4) find that most of the serviceable procedures or principles which arise in

of muscular movements, partly by idiosyncracy, partly by the mood and the associations present at the time, until finally a picture that will 'suit' is built up in this trial and error fashion."

[2] Ladd and Woodworth, Elements of Psysiological Psychology, 1911, p. 550, in referring to the 'trial and error' method of learning, say,—"We prefer to call it learning by varied reaction through selection of the successful variants."

[3] Figures refer to Bibliography at end of article.

[4] E. L. Thorndike, The mental life of the monkeys, *Psychol. Monog.*, III, 5, 1901, p. 2.

the course of the learning, are hit upon by accident. This finding is leading psychologists to question the existence of a specifically human type of learning to meet situations.

The term 'trial and error,' however, is still current in the sense in which Jennings (19) employs it to describe the behavior of Paramecium. Jennings points out that Paramecium's reaction to an obstacle in its path is of a single sort,—the avoiding reaction. If this reaction does not bring immediate success, it is repeated again and again until the animal ultimately succeeds in avoiding the obstacle; Baldwin has called this the 'try, try again' method. It is in this sense that the term trial and error is employed in the present study of mirror tracing. However, as we shall note later, the human subject employs many sorts of reaction in any given situation, instead of having recourse to but one reaction, as in the case of Paramecium.

The details of trial and error learning have never been investigated in any thoroughgoing fashion, except in the domain of animal behavior; and it would carry us too far afield to refer to all of these animal studies here. However, in later sections of this paper, we hope to touch upon certain problems which these studies have raised.

Investigations by Perrin (34), by Hicks and Carr (16), and by Starch (42) have discussed certain phases of trial and error learning in man. Hicks and Carr investigated the procedure of children and of white rats in learning to find their way through a maze; Perrin studied the adult's procedure in solving a similar problem. The act of learning investigated by Starch consisted in tracing a figure by mirror reflection.

In the opinion of the present writer, none of these studies have attempted to bring the trial and error phase of human learning into relation with later developments in the process of learning. They have usually assumed that learning begins with a process of trial and error and ends in a 'controlled' and 'purposeful' procedure, and they have made no serious attempt to supply the intermediate links between these terminal points. Most of the discussions of the topic of learning which one finds in the textbooks are open to the same criticism; Watson (53) is a notable exception to this criticism.

II. EXPERIMENTAL PROCEDURE

1. Apparatus

Several forms of apparatus were employed in this investigation; all of these, however, were variants of the six-pointed star, with certain accessory mechanisms.

Apparatus I. This ~~initial form~~ of apparatus consisted of a 'star' design and a recording mechanism. The former was constructed as follows: A regular and equilateral star, whose extreme width was 17 cm., was cut from a sheet of brass one mm. thick, and was mounted upon a glass plate six mm. in thickness. By this means we obtained a path, in the form of a six-pointed star, which was six mm. in width, whose edges were of brass, and whose base was of glass. (Fig. No. 1.) The task assigned to the learner consisted in learning to trace this path, as seen by reflection in a mirror, without touching the brass border. Earlier experiments had revealed a tendency on the part of certain learners to slide the metal stylus along the edge of the path, keeping the former in contact with the latter throughout; in order to eliminate this procedure, niches were cut at intervals along the brass border. There were four of these niches on each of the twelve sides of the six-pointed figure,—the niches being three mm. wide and three mm. deep, so that they were large enough to admit the point of a stylus. The stylus was made of brass with an ivory tip, and was of the size and form of an ordinary lead pencil. The two brass plates, whose edges constituted the edges of the path, were connected with a binding-post at the edge of the glass plate (*A*, Fig. 1). A metallic brush-contact was inserted into a second binding-post in such fashion that it extended out over the path at the starting point, (*B*). A flexible copper cord connected the upper end of the stylus with a third binding post, (*C*).

The recording mechanism consisted of a kymograph which carried an endless sheet of white paper. Three fountain pens, which were attached to three electro-magnets, were in contact

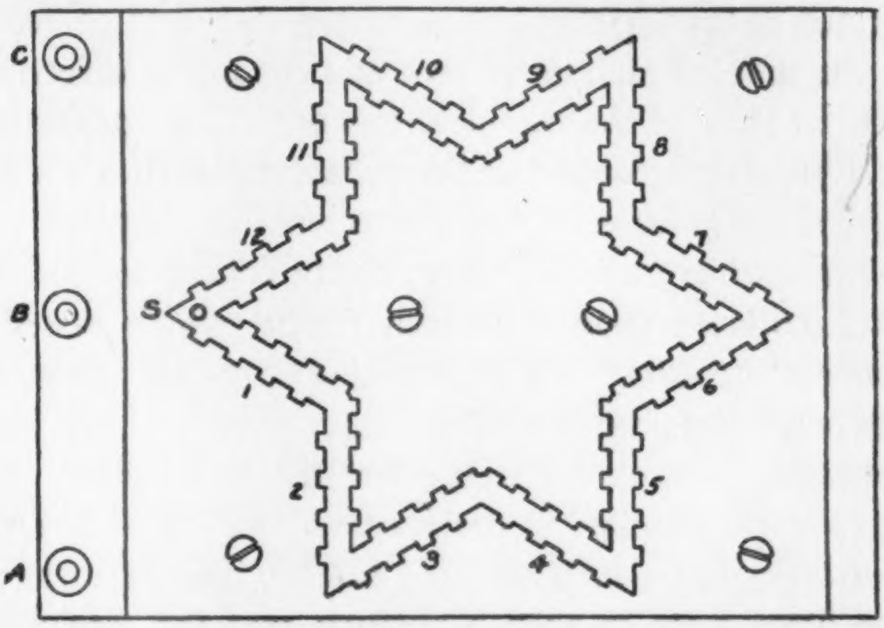

FIG. 1. This is a drawing showing the "star" apparatus employed in this investigation. The starting point for tracing the diagram is the small circle to the right of the point *S*. See text for details of the construction of the apparatus.

with this band of paper. One of these electro-magnets was in circuit with the two brass plates which constituted the margins of the outline of the star; this electro-magnet, with its pen, recorded any contact which might be made between the stylus and the edge of the path. The second electro-magnet was in circuit with the brush contact in the path of the star; and indicated the beginning and end of a circuit. The third electro-magnet was in circuit with a Jacquet chronometer, and by this means a time line, marking fifths of a second was recorded, (Fig. 19, p. 61).

The star was placed upon a flat-topped laboratory table, which was of convenient height for writing. A mirror 18 cm. by 20 cm. was fixed on the table in a vertical position, with its reflecting surface turned toward the star. A screen of green blotting paper was fastened in such a position that the subject could readily and conveniently see the mirrored image of the star, but he could not see the star itself. The apparatus was adjustable so that a natural and convenient posture of the learner was secured throughout the experiment.

Apparatus II. This second form of apparatus was designed for the two-fold purpose of furnishing an accurate and detailed graphic record of every movement and change of direction made

by the stylus in tracing the outline of the star, and of recording not only the time of each movement and change of direction, but also the total time of the complete circuit. This apparatus consisted of a 'tapping recorder' and duplicate copies of a six-pointed star. The tapping recorder was constructed as follows: A thin plate of brass, thirty-five cm. long, thirty cm. wide, and 1 mm. thick, was mounted upon a wooden frame, which rested upon four wooden supports. This formed a box-like structure, of which the brass plate constituted the top. Pieces of felt were inserted between the wooden frame and the brass plate, and the latter was loosely attached to the frame by means of screws. A large electro-magnet, which actuated a heavy hammer, was placed below the brass plate in such a position that the stroke of the hammer was received at the center of the plate. The sheet of paper which bore the diagram of the star was clamped securely to the upper surface of the brass plate; a second sheet, bearing a duplicate diagram of the star, in perfect register, was introduced between the first sheet and the brass plate, and a sheet of carbon paper was inserted between these two diagrams.

A mirror and a screen were arranged in positions similar to those described in our initial form of apparatus. The electromagnet was in circuit with a battery of dry cells and a Jacquet chronometer in such fashion that each beat of the chronometer was attended by a hammer stroke upon the under side of the brass plate. Each stroke of the hammer caused a slight movement of the plate and recorded a dot on the line traced by the stylus; hence the record shows the detailed movements of the stylus, together with the time of each movement. (A sample record is shown in Figure 9, p. 41).

Before beginning this group of experiments the learner was given considerable practice with this mechanism, during which details of various sorts were traced in free-hand fashion in direct vision—this being done in order to make sure that the tapping did not interfere with the free movement of the stylus, and in order to familiarize the subject with the apparatus. It may be added that no such interference was detectable; signatures which our subjects wrote under these experimental conditions could not be

distinguished from their usual signatures, excepting that the time-dots were present in the former case.

Apparatus III. This form of apparatus was a slight modification of that employed by Freeman (14)[5] in his investigation of handwriting. The essential features of this apparatus were as follows: A continuous band of adding machine paper is drawn across a flat writing surface by means of an electric motor; over this moving band is laid a stationary sheet upon which the observer writes with an ordinary lead pencil. The reader is referred to Freeman's two papers (op. cit.) for an elaborate and accurate discussion of the technique involved in the measuring of the time of hand movements by means of this apparatus.

In our modification of this apparatus we employed a plate fibre-board from which two sides of the star (sides 3 and 4, Fig. 1) were cut out in the same way as these two sides were cut out of brass in our metal star,—the two grooves thus furnishing paths whose directions were at right angles to each other. This fibre plate was fixed to the writing surface in such fashion that when the subject sat before the apparatus, the path to be traced lay directly before him in the form of an inverted V; the moving band of paper passed under this V, moving from right to left. After each circuit of the diagram had been completed, the primary record and the secondary record (upon the moving band) were filed away and preserved together. A sample of one of these primary records is shown in Figure 12, p. 49).

This apparatus was used in making a detailed investigation of the learning in the case of two sides of the star which proved to be very difficult; it enabled us to determine the time of each movement, the time of each pause, and the location of each pause. In this group of experiments we employed unpracticed learners who had never had any previous experience in mirror-tracing; but we also employed this apparatus with certain of our practiced learners in order to make a more detailed investigation of certain features of their behavior while tracing at high speed.

[5] Also, An experimental analysis of the writing movement, Psych. Rev. Mono. Vol. XVII, No. 4, will be very helpful to the reader in understanding this apparatus.

Apparatus IV.[6] The object of this fifth group of experiments was to obtain an accurate photographic record, with time determinations, of all the movements made by the observer in tracing the path of two of the more difficult sides of the figure. The method was as follows: The path to be traced was drawn upon a sheet of coordinate paper. Tracing was made by means of an ordinary adjustable pencil which carried (just above the writing-point) a small rice-grain electric bulb, and this bulb was in circuit with a tuning-fork (twenty-five vibrations per second). The bulb was shielded by a small cup of hard rubber. The diagram to be traced was mounted on a flat table in a position convenient for writing; above the diagram was a frame which carried a camera, in such a position that the lens of the camera was directly over the diagram.

Before the observer began his tracing the photographic plate in the camera was exposed to the diagram; then the lens was closed for a time while the tuning-fork was being set in vibration, thus causing a series of flashes (twenty-five per second), in the lamp at the pencil-point. The lens was opened again when the learner began to trace the figure with his pencil. The photographic record of this tracing shows the path followed by the learner in making the tracing, and also the time measurements, made in one-twentyfifths of a second. A sample record from this machine is shown in Figure 10, p. 47.

This apparatus was employed chiefly for the purpose of comparing the tracing of a slightly practiced learner with the tracing made by the same observer after he had reached high speed,—the prime object of this apparatus being to furnish a more accurate and detailed record of the temporal relations.

2. Method

All of our experiments were performed in the Psychological Laboratory of Clark University; excepting a few experiments conducted at the University of Utah for objective data only. All

[6] We are indebted to Mr. Frank G. Gilbreth, of Providence, R. I., not only for the loan of valuable apparatus employed in this group of experiments, but also for numerous valuable suggestions.

of our data will be referred to the type of apparatus employed and the condition of the subject (practiced or unpracticed, beginner or advanced learner). We sought to obtain data from objective and introspective sources at every stage of the learning. In our introspections the observer[7] first reported his description in detail; this was then followed, where necessary, by careful questions which were designed to clear up obscure points, and to give the experimenter a clearer understanding of the procedure and processes involved. Where questions were employed, their exact wording was recorded and will be noted in our quotations.

Every effort will be made to keep conditions uniform throughout the practice of each reagent. The apparatus was explained in detail before the experiment began, by which means we hoped to secure a constant and uniform behavior from each learner; since any curiosity on the part of the learner,[8] regarding the use of the apparatus, was satisfied at the outset and his attention was left free for the experiment. We were frequently amazed by the constancy of behavior of the learners, and at the almost complete absence of irrelevant and disturbing elements.

Since all of our apparatus involved the tracing of a diagram by means of a stylus or pencil, care was taken throughout that the height of the tracing surface, and the distance of the hand from the body, should be similar to these requirements in the ordinary act of writing. The learner sat in a comfortable, cushioned chair; and efforts were made to secure perfect quiet in the experimenting room. In those cases where a slight noise arose from the operation of the apparatus, our learners assured us that this did not constitute a distracting factor; and this statement is abundantly verified by our introspections.

In an early stage of our preliminary investigations, it was noted that the instructions and the distribution of practice were important factors in the learning. Accordingly, we decided to vary

[7] Throughout this paper the learner who also furnishes an introspection of his learning will be arbitrarily designated an 'observer' while the learner who furnishes merely objective data will be referred to as 'subject'; under certain conditions a learner may act in both capacities.

[8] A special instance of this was the question,—'Will I get an electric shock from the apparatus?'

both the instructions and the practice periods in such fashion as to furnish positive data regarding the influence of these two factors. In the descriptions and discussions which follow, we shall make frequent use of the terms 'recess period,' 'recess period practice' and 'series practice.' By recess period we mean that period of time which the experimenter interpolates between successive efforts of the learner. Each such effort is a unit of practice; it may involve a tracing of one side of the star, or a tracing of the whole star. The term 'recess period practice' refers to that practice in which a recess period appears before each unit of practice, whether this latter be a tracing of the third side of the star or a circuit of the whole star. The term 'series practice' refers to that practice where the unit is repeated one or more times without the intervention of a measurable recess period,—for instance, five circuits of the star made in immediate succession without any intervening recess period, would constitute a series practice.

Three types of instruction were employed in this investigation. In the first type the instructions were as follows: "Attend to both speed and accuracy in going around the star; that is, avoid touching the sides of the path, and go around as fast as possible," (speed and accuracy instructions). Care was taken to repeat these instructions at least twice to the learner.

Since the two factors, speed and accuracy, might differ in value according to the order of their mention in the instructions, the order was reversed in the second type of instruction, where it was as follows: "Go around the star and avoid touching the sides; your efficiency will be measured solely in terms of your accuracy," (accuracy instructions). In the third type of instructions, the learner was instructed as follows: "Go around the star as fast as you can; your efficiency will be measured solely in terms of your speed," (speed instructions).

We were also interested in testing out some of Langfeld's (23) conclusions on the effect of instructions; accordingly, we modified our instructions so that the subject was instructed as follows: "You will trace around the star, keeping the stylus in the middle of the path."

After one group of conditions had been investigated we

changed the instructions in order to investigate the effect of such change. Throughout our discussion the data will be referred, in every instance, to the instructions under which these data were obtained.

Various distributions of practice were investigated; each learner, however, was kept under constant conditions until the effect of those conditions had been investigated. It was our aim to obtain data regarding both recess period practice and series practice at every stage of the learning, and to correlate these two types of practice with the type of instructions. In other words, we were concerned, not with the economy of learning, but with the effect of the instructions; it was our aim to discover the correlation between distribution of practice periods and the attainment of a high degree of accuracy or of speed under specific instructions.

3. Learners

In our investigation we employed twenty-one learners; nine of these were used for securing objective data and introspection, and twelve were used for objective data only; the former are designated 'observers,' and the latter, 'subjects.' Our observers were all graduate students in the department of Experimental Psychology in Clark University; the first two in the following list of observers having attained the doctorate and the remaining seven, the master's degree in psychology. Our subjects were advanced students in Clark College, Clark University, and the University of Utah. The learners will be referred to throughout this paper by number only. A college class of advanced students from the University of Utah was also used in two group tests.

Observers: (1) S. W. Fernberger, (2) Sara C. Fisher, (3) H. R. Crosland, (4) B. W. DeBusk, (5) Florence Mateer, (6) F. J. O'Brien, (7) Bruce B. Robinson, (8) R. B. Teachout, (9) R. H. Wheeler.

Subjects, for objective data only, were:
(10) Ethel Bowman, (11) G. A. Coe, (12) Ruth Dunlop, (13) Florence Groshell, (14) Chinaki Kageyama, (15) Eva Kass, (16) M. C. Knapp, (17) Yashihide Kubo, (18) H. C. Lewis, (19) D. I. Pope, (20) Loren Richards, (21) Rex W. Williams.

III. RESULTS

1. The Learning Curve: Correlation Between the Effect of the Instructions and the Distribution of Practice.

A. General Character of the Learning Curve

As the reader will observe by referring to Figures 5, 6 and 7, the nature of the curve for this type of learning is dependent both upon the instructions given to the subject and upon the distribution of practice. When a mixed practice (recess period followed by series practice) is given, the results of which are shown in Figs. 5 and 7, the general trend of the average curve—the arithmetical average of the time and error quantities—is similar to that obtained by using animals in a maze.[9]

The curve may very readily be divided into two distinct parts: First there is an initial drop where great improvement takes place and where, in most instances, the time and error curves are parallel; and second, a plateau stage, where there is much less improvement and where the time and error curves may often, as in Figs. 4, 6 and 7, tend to vary in opposite directions. If a curve representing the arithmetical average of the time and error quantities should be drawn between the time and error curves in Fig. 7, a curve of logarithmic character is obtained which is roughly similar to that obtained by Ebbinghaus in his investigation of forgetting. In our analysis of the learning curve we shall secure better results, however, if we take up a consideration of the type of curve secured under every possible combination of instructions and distribution of practice; which we shall proceed to do in the following sections.

B. The Learning Curve under Accuracy Instructions

a. *Series Practice from the Beginning of the Learning.*—By referring to Fig. 2 the reader will observe that no improvement

[9] The reader is referred to Thorndike's Animal Intelligence, Macmillan, New York, 1911, and to Watson, Behavior, Henry Holt, New York, 1914, for numerous examples of such curves.

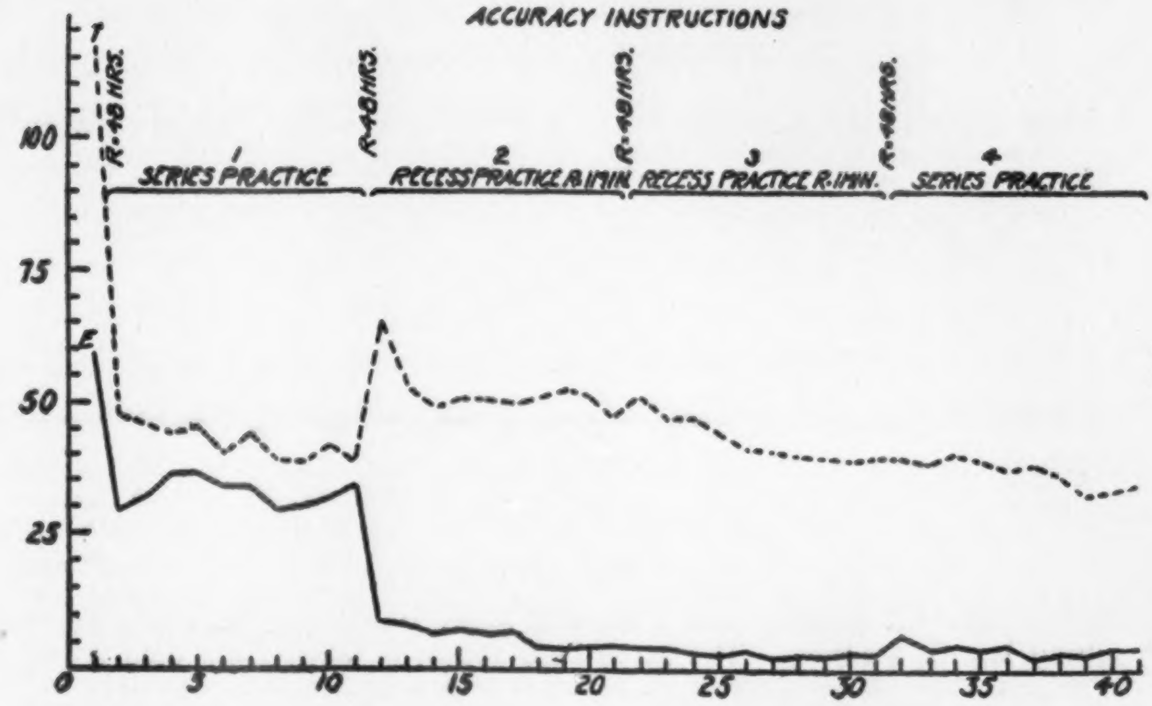

FIG. 2. A diagram showing the average learning curve of ten subjects working under various conditions of practice. From the scale at the left may be read the time in seconds and the number of errors. The horizontal scale indicates the successive circuits of the star. It should be noted that the improvement in accuracy (errors) is confined to the recess period practice. The rise of the time curve in Part II is an *irradiation* curve. The quantitative data for each subject are shown in Table II, p. 79.

took place in accuracy while these subjects were working under series practice conditions. The instructions stressed the avoidance of errors and no limitations were placed upon the time required to make the circuit of the star; the subjects were striving merely to avoid errors. This same state of affairs obtains with all our subjects working under the same conditions. This experiment has been performed with thirty objects during the course of our work and we have never succeeded in getting appreciable improvement under such conditions. No improvement at all occurred except in the case of three subjects who show slight improvement. This is true only when the subjects have had no experience with mirror tracing, which is essential for this case, as later results will show that this state of affairs holds only for the initial drop of the learning curve, (Fig. 21, p. 65).

b. *Recess Period Practice throughout the Learning.*—Under this form of practice the accuracy instructions were used and the circuits of the star were separated by recess periods. Reference

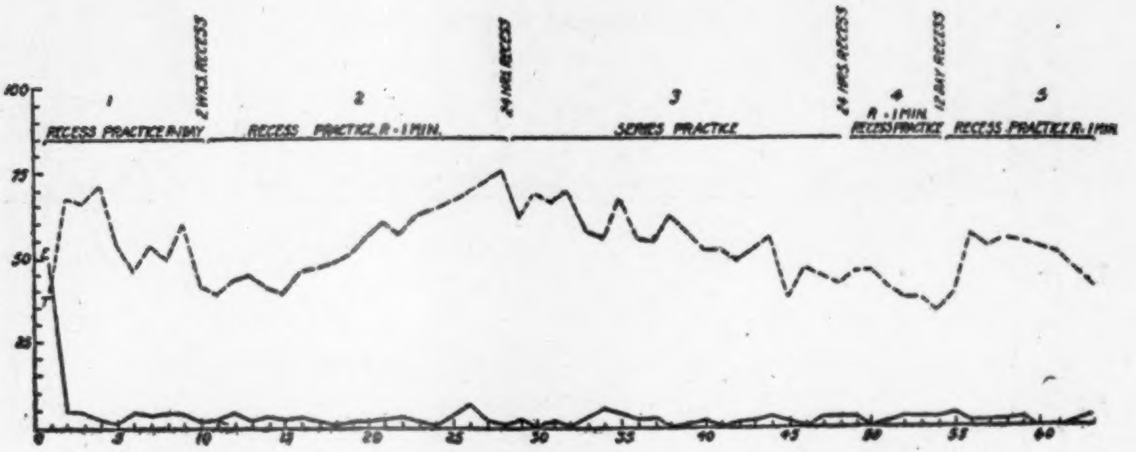

FIG. 3. Ordinate indicates time and errors; abscissa, successive circuits. This learning curve was secured from the work of subject No. 13; accuracy instructions were employed throughout. Part II of the practice shows a very marked irradiation curve. It should be noted that series practice in Part III brings about a marked improvement in speed without resulting loss in accuracy. The curve here shown is taken from data secured after the subject had completed a recess and a series practice, such as is shown in Part I of Fig. 2.

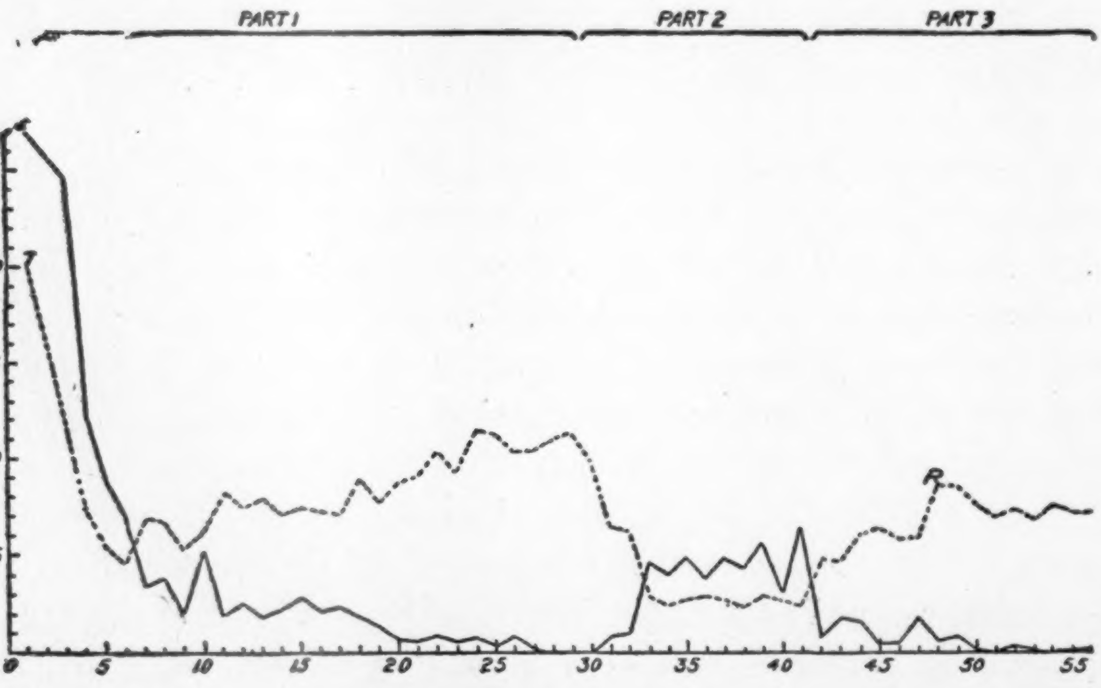

FIG. 4. Ordinate indicates time and errors; abscissa, successive circuits upon apparatus I. This is a curve of Subject No. 14, secured through a practice of one circuit of the star per day. Part I was secured under accuracy instructions, Part II speed and accuracy, Part III under accuracy instructions. The point *R* indicates a recess period of eight months. It should be noted that, by the ninth circuit, the subject had reached the limit of his improvement, under recess practice conditions, as measured by the arithmetical average of the time and error quantities; thereafter, he makes a choice of one element and neglects the other.

to Fig. 4, will show that, under recess period practice, the improvement in both accuracy and speed in the early stages of the learning, is very rapid; but this is followed by a change of direction of the time curve. This marked rise of the time curve is explained in our objective and physiological analysis of the learning as irradiation; which has led to our naming this type of curve, an *irradiation curve,* (page 51).

The time curve is seen to rise progressively for a number of circuit; the increase in time is paralleled by a fall (improvement) in the error curve. This type of curve is found under no other conditions than recess period practice with accuracy instructions. The rise in the time curve is followed by a fall, provided the practice is continued sufficiently long, Figs. 2 and 3. It should be

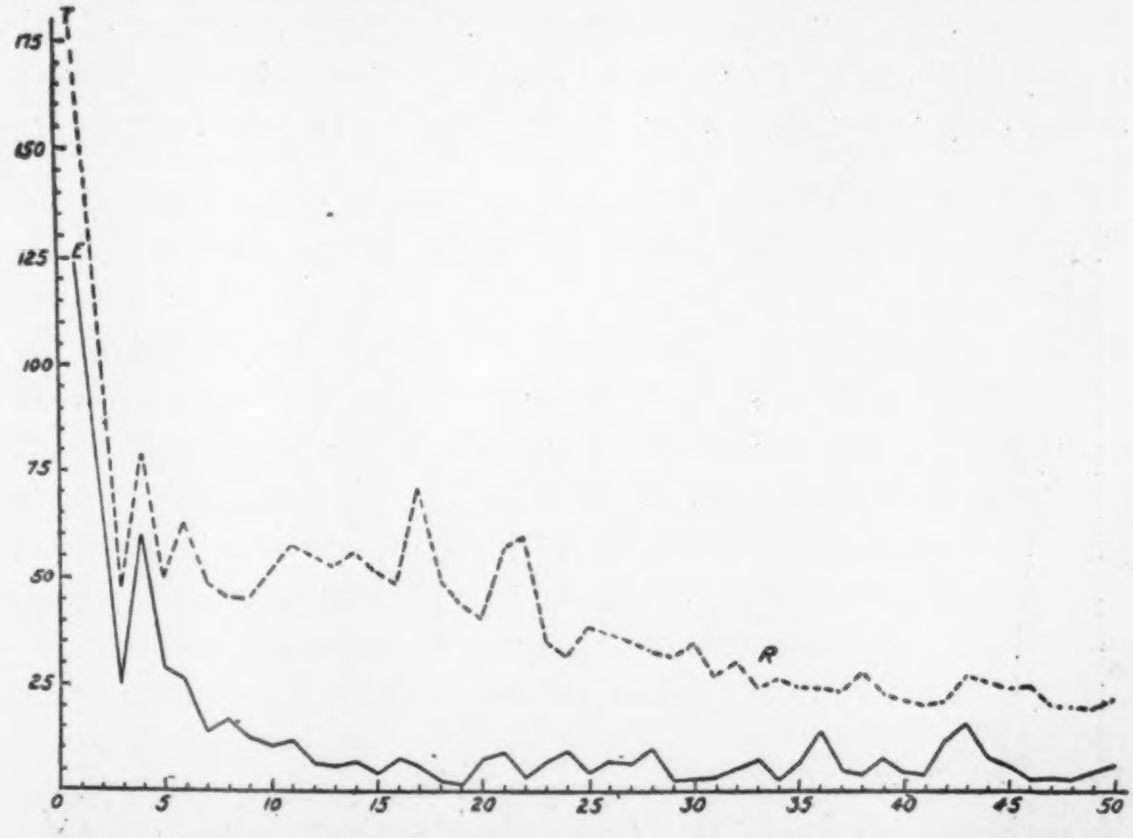

FIG. 5. Ordinate indicates time and errors; abscissa, successive circuits upon apparatus I. This is the curve of Subject No. 17, secured under accuracy instructions. One circuit per day was the scheme for the first two circuits; thereafter, two circuits in series per day was the practice. It should be noted that there is a simultaneous fall of both time and error curves throughout the learning,—a marked contrast to state of affairs in Fig. 4 where recess period practice is maintained throughout. The fourth circuit, the first not to be preceded by a recess period, shows a loss in both time and errors; this would not have occurred had the initial drop in the learning curve been completed before the series practice was begun. The point R indicates a recess interval of eight months.

noted that there is no reversal in the error curve, which, on the contrary, may show improvement or remain unchanged so long as constant conditions are maintained.

c. *Recess Period Practice at the Beginning, followed by Series Practice.*—The effect of this set of conditions is clearly shown in Fig. 5. In Figs. 2 and 3, it is seen that, at certain later stages in the learning, series practice is of positive advantage; the negative improvement in the time curve is reversed, while there may be no loss in the error curve.

C. The Learning Curve under Speed and Accuracy Instructions

a. *Series Practice from the Beginning of the Learning.*—Under these conditions the quantitative results are identical with those secured under series practice with accuracy instructions, as noted above. Our introspective results (see a later section of this paper) show, when the element of speed is included in the instructions to beginners, that, after the first few strokes, the instructions

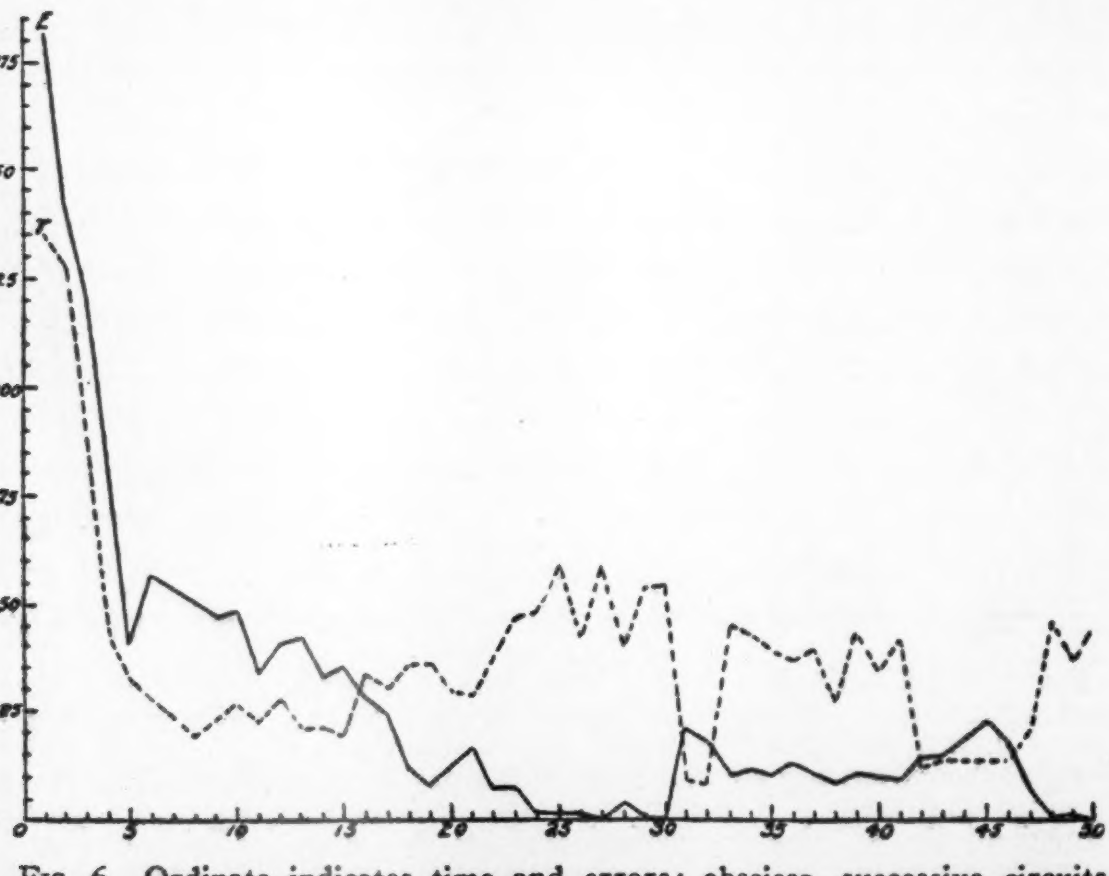

FIG. 6. Ordinate indicates time and errors; abscissa, successive circuits. Curve of Subject No. 16, secured under speed and accuracy instructions, with recess period practice of one circuit per day. Note that both the time and error elements alternate as in Fig. 4, thus indicating that the basis of the alternation is the recess period practice and not the instructions to the subject.

are "discounted" and the subject proceeds to trace the star with an 'accuracy only' *Aufgabe*. No improvement at all can take place in the early stage of the learning until a recess period is inserted between circuits,—a case we have already discussed.

b. *Recess Period Practice from the Beginning of the Learning.*—Fig. 6 presents a learning curve secured under these conditions. In this curve it will be observed that the early high rate of improvement is shown in both the time and error curves. Throughout the remainder of the curve there appears to be an alternation in the improvement of the time and errors, i.e., a selection of one or the other element of the learning. In other words, it seems that the attention of the subject may be directed to an elimination of errors or to the securing of a high rate of speed, but may not be directed to both simultaneously; at any rate a high degree of efficiency cannot be secured in both elements of the learning at the same time, excepting in the very earliest stage of the learning, which we have called the initial drop of the curve. In later sections we hope to show why simultaneous improvement cannot occur in the time and error curves under recess period practice conditions.

c. *Recess Period Practice at the Beginning of the Learning, Followed by Series Practice.*—Under these conditions we secure a learning curve (Figs. 5 and 7) which shows improvement in both time and errors while the recess period conditions are being maintained during the initial drop of the learning curve; and a persisting improvement occurs in speed throughout the mixed recess and series practice. This type of time curve has never been secured under any other conditions, which may be taken to show the function the series practice performs in securing improvement in speed without loss in accuracy. It should be noted that the practice conditions here are mixed, i.e., recess period practice for the first stage of the learning, and recess and series practice during the remainder of the experiment. This type of practice has uniformly given us the highest net efficiency,[10] the most uni-

[10] Throughout this study we have avoided the use of any mathematical formula for computing efficiency. Such a formula would necessarily involve both the time and error quantities and consequently would lead to definite

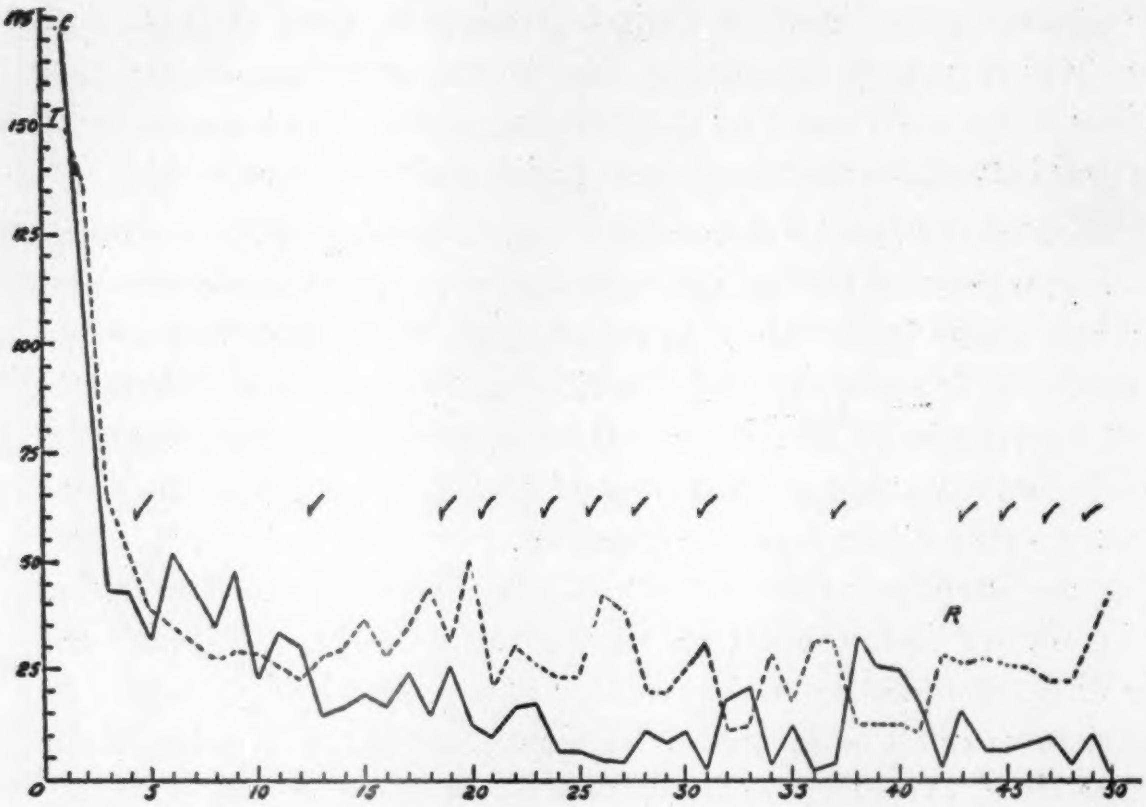

FIG. 7. Ordinate indicates time and errors; abscissa, successive circuits. Learning curve of Subject No. 6, secured through recess period practice, one circuit per day, for the first four days, and mixed series and recess period practice thereafter. The check (V) marks indicate recess periods of at least one day; circuits not so indicated were in series. Note the synchronous fall of both time and error curves up to the thirtieth circuit. The point *R* indicates a recess period of nine months.

form learning curves, and is precisely that type of practice which is usually found in the uncontrolled learning of practical life; excepting that, in the latter, the recess period is usually not purposely inserted in the early stages of the learning.

D. Discussion

From the foregoing presentation of learning curves the reader will observe that the two important objective factors in the learning are the recess period and the instructions to the subject. We have seen that the recess period conditions the improvement in

loss, since, in that case, we should lose sight of the changes taking place in each element of the learning under the different conditions of practice; and it is just such changes which seem to be clearly shown by our simple learning curves, indicating both the time and error quantities. Whenever a general unanalytical term, showing improvement in a rough way, was desired, we have employed the arithmetical average of the time and error quantities.

accuracy in the first stage of the learning; while, in later stages of the learning, improvement in speed, without a resulting loss in accuracy, is dependent wholly upon series practice or a long repetition of recess period practice.

Later sections of this paper will show that there are two types of improvement in speed; one occurs during the initial drop of the curve and is due to a shortening of the path taken by the stylus in tracing the star, and to the elimination of delays when the stylus is caught in the niches,—this improvement in speed results indirectly from the gain in accuracy; and, there is an improvement in speed of another type, which results from a physiological change—facilitation—in the neuromuscular apparatus, brought about by series practice or a long repetition of recess period practice.

The conclusions which we have reached in this preliminary survey of our data may be summarized as follows:

(1) Without the recess period practice under accuracy instructions, the initial drop in the learning curve,—the place of greatest improvement,—cannot be secured; in fact, no permanent improvement in accuracy may be secured in the early part of the learning, without the interpolation of a recess interval between the circuits of the star, Fig. 2.

(2) If the recess period practice, under accuracy instructions, is continued beyond the initial drop in the learning curve, the time curve, will show a change from positive to negative improvement, —our irradiation curve,—and thus continue to show progressive loss, until, through repetition, it begins to show positive improvement; while the error curve continues to show improvement, or remain stationary, throughout the practice, Figs. 3 and 4.

(3) After the initial drop in the learning curve is completed, mixed series and recess period practice will lead to a simultaneous improvement in speed and accuracy, Figs. 5 and 7. Recess period practice under the same conditions leads to improvement in but one element selected by the learner, either speed or accuracy, and to a loss in the element not selected,—thus, when accuracy is chosen the time curve becomes our irradiation curve, Figs. 4 and 6.

(4) Recess period practice leads to deliberate, slow movements, favoring accuracy; series practice leads to rapid movements and favors speed, Figs. 2 and 3.

(5) In general summary, we may say that in the first stage of the learning, the recess period is the important factor, and emphasis upon accuracy is encouraged. In later stages of the learning, series practice becomes necessary, which secures simultaneous improvement in speed and accuracy, making the speed and accuracy instructions appropriate.

2. Introspective Analysis of the Learning

By far the greater part of our introspections are drawn from work with our first form of apparatus. This apparatus was chosen largely because the time of making a circuit of the star was short enough to admit of detailed introspective analysis, and also because the geometrical form of the star,—its being divided into twelve equal parts, greatly aids the learner in recalling the details of his experience. Another factor which facilitated introspection was due to a second mechanical feature of the star. By referring to Figure 1, it will be seen that the star is so constructed that, when the learner is seated directly in front of the apparatus, four of the sides of the figure run in a direction which is parallel to the median plane of the body and eight sides run obliquely to this plane; the former we have called 'vertical' and the latter 'oblique.' The mirror reverses the direction of the oblique lines so that the mirror image runs nearly at right angles to the true direction of the groove; the four grooves which are parallel to the median plane of the body are changed in the mirror image through one hundred and eighty degrees and, in tracing the star, one moves in a direction which is exactly opposite to the apparent direction. The learner soon discovers this reversal, and from the second circuit of the star he finds that these four sides are very easy to trace.

The star is thus divided, for the learner, into difficult and easy sides after the first circuit of practice. This differentiation was found to be of the highest value in securing an analysis of the learning difficulties; since the difficult directions are contrasted

with the easy directions in the learning situation. The oblique sides vary in difficulty from time to time with each observer; but they are always the most difficult parts of the star for every observer. Experiences which have to do with these oblique or difficult sides stand out prominently in our introspections.

Our introspections reveal the fact that in every respect the learning of mirror tracing is of the true trial and error sort. In a few instances, in the earlier stages of the learning, subjects would attempt to 'reason out' the true direction of the grooves; but in all cases, in our experiment, this was immediately abandoned as of no value, and the subjects fell back into the stage of trial-and-success striving, until, by the accumulation of successful movements, they finally succeeded in making a circuit of the star. The first successful movements are made accidentally, so far as the conscious experience of the learner is concerned.

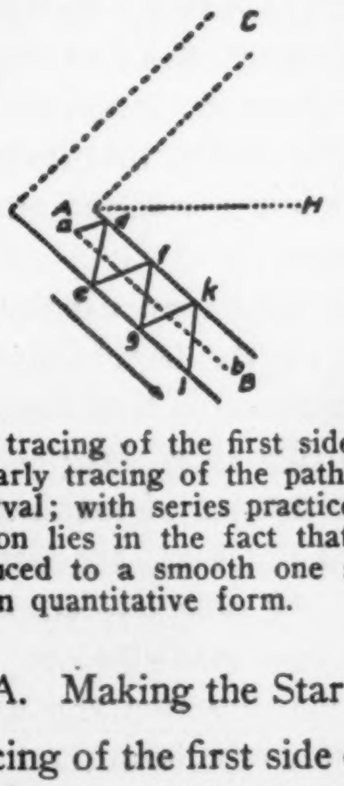

FIG. 8. A diagrammatic tracing of the first side of the star. The zigzag path *ad, de, ef, fg* is an early tracing of the path *AB*, while *ab* is the first tracing after a recess interval; with series practice the zigzag path remains. The diagrammatic distortion lies in the fact that a few subjects will not have the zigzag path reduced to a smooth one so quickly. Figs. 2-7, inclusive, show these facts in quantitative form.

A. Making the Start

In beginning his tracing of the first side of the star, the learner employs a movement which would be appropriate for tracing this side if the apparent direction were the true direction of the path; that is, his movement is practically at right angles to the true direction of the path. This movement leads to the stylus being caught in a niche on the right hand side of the path, *d* Fig. 8. The subject endeavors to withdraw the stylus but each effort

serves to force it more tightly into the niche; the attempts to withdraw are repeated again and again, the subject endeavoring, subjectively, to withdraw, while, in reality, he is forcing the stylus more tightly into the groove.[11] Our objective results show that some subjects remain in the first niche as long as seventy seconds; this, however, is exceptional.

During the period when the stylus is caught in the niche a gradually increasing strain develops in the muscles of the fingers, wrist and arm, and finally includes the muscles of the back. There is an increasing tension in the muscles of respiration which is accompanied by at first a partial, and at times, a total inhibition of breathing. The whole experience is unpleasant and in some cases is described as painful, especially after the experience has persisted for some time; this is terminated by a relaxation, and in some cases a 'giving up,' the degree of this relaxation varying with the observer. In most cases there is complete relaxation in the tensions of the arm and body; the observer often falls back in the chair, but this does not occur in all cases. The most characteristic physiological change is that which takes place in the respiratory apparatus; this consists in a relaxation and then a complete reinstatement of breathing.

The state of general relaxation usually continues for a short time; it is terminated by the beginning of imaginal processes which are directed to discovering the true direction of the groove. At this time there are often visual images of the groove and kinaesthetic manual-motor images of making movements down the groove. These imaginal processes are immediately cut short by a return of the eyes to the objective situation. Quite often the movement which had been made before and which constituted the attempt to go in the direction the mirror indicated, is repeated; and following this repetition there is often a complete reversal of the movement made.

This new movement (*de.* Fig. 8) is brought about by the opera-

[11] In connection with this procedure of the subject an interesting thing occurs. He often reports to the experimenter that the sides of the star are magnetized and consequently are holding the stylus tip against the edge of the path; while, in reality, the subject is moving in a direction contrary to his subjective awareness.

tion of those muscles which are, physiologically, antagonistic to the muscles controlling the first movement made by the observer. It is our belief that this reversal is purely reflex and can be accounted for by the laws of physiological reversal,[12] since the observer introspects that he 'found his hand moving in the proper direction.' This movement carries the stylus to the niche at *e*, and here the state of stress and strain which occurred at *d* is re-experienced, except that it endures for a much shorter time: all of which is followed by a reversal of the last movement (*de*). This new movement is inhibited by pressing the stylus downward at *f* and swerving in the direction of *g*,—a process continued throughout all the difficult sides.

While our description here is schematic, in the sense that the reactions of many subjects are, at first, much more complicated; yet, it is essentially true for all, and is duplicated precisely in some of the reactions of all of our subjects. Those whose reactions are more complicated at first will eventually reproduce a pattern as simple as the above. Throughout the execution of these movements, the observers introspect that they *accidentally* make the movements which lead them out of the difficult niches; the reversal of movement, when it does come, is so quick that it takes place wholly without conscious direction.

B. Preliminary Analysis of a Circuit

The first side is much the most difficult side during the first circuit of the star. Having traversed the first side, the observer has little difficulty with the second side,—the reader will observe (Fig. 1) that this is one of the sides running parallel to the median plane of the body. The path of the stylus on the second side is usually a straight line and is made at much higher speed than the first side. The second side is one of the subjectively 'easy' sides; and the tracing here is always accompanied by a marked feeling of pleasantness; the observers invariably introspect that this side is made with rather long, sweeping movements. When the turn toward the third side is reached, the

[12] Our section on the objective analysis of the learning situation will discuss at some length the physiological points here involved.

observer meets with another difficulty; this is another oblique side which runs at an oblique angle to the median plane of the body.

The zigzag movements, made on the first side, are instituted again on the third side; the progress up the side proceeds in exactly the same fashion, but is usually more rapid than on the first side. Here the introspections show that the successful movements, as in the case of the first side, are hit upon by accident. The tracing is characterized by unpleasantness which in some cases is described as more intense than on the first side; the time is usually not quite so long as in the tracing of the first side, but the errors are often much less. The zigzag strokes are in many cases inhibited by a downward pressure on the stylus which is responsible for the reduced number of errors. These inhibitions are reflex and come when the stylus is seen to approach the side. Many of the observers refer the unpleasantness which is experienced in tracing an oblique side to these inhibitions of the forward movement.

The fourth side is another of the oblique sides and consequently is one of the difficult sides where the zigzag course of the stylus is continued. The time of the tracing and the number of errors usually remain about the same as on the third side; and, when a subjective estimate of the difficulty is asked for, it is usually reported as difficult as the third side. The fifth side is one of the easy sides, and the path of the stylus here is straight and few errors are made in tracing it; and this side is quite often described as being a resting place where the observer relaxes a little after his efforts made on the third and fourth sides.

The sixth and seventh sides are found to be difficult; the zigzag course of the stylus appears again; the errors and the time remain about the same as on the third and fourth sides. The special difficulty connected with the seventh side consists in the fact that it extends to the left. On all of the oblique sides thus far, the stylus has moved toward the right; and the turning to the left, which now begins, is especially hard to acquire, certain learners reporting that this is by far the most difficult of the sides.

Having traced the seventh side, the remainder of the star seems to be comparatively easy. The oblique sides are relatively diffi-

cult, however; but they are usually reported to be much easier than the oblique sides in the first half of the star. The twelfth side varies in difficulty with the different subjects, yet it is almost always one of the first of the oblique sides to become easy. The imaginal material reported by the subject throughout the tracing is very meager, when working under accuracy instructions, and none of the observers has ever reported the presence of a control image during the first five circuits of the star.

After this preliminary survey of a circuit of the star, we take up our introspective analysis in detail, quoting freely from the introspections of our observers.[13] These introspections will be drawn from different stages of the learning because of the contribution which they seem to make to the analysis of such stages.

C. The Reflex Nature of the Learning

a. *Getting Out of a Difficulty.*—As noted above, the first movement the observer makes is in the wrong direction and goes in the apparent direction of the groove. The experiences here are characterized by an awareness of repeated efforts to withdraw the stylus; these are merely attempted movements which go in the wrong direction and serve to drive the tip of the stylus more tightly into the niche. These efforts are ultimately followed by a general relaxation and a temporary shift of the visual attention away from the details of the niche. Attention soon returns to the general situation again, and the second visual perception of the stylus in the niche is followed by more attempts to move in the wrong direction and then there comes a reflex reversal of the first movement. The following introspections are typical descriptions of this phenomenon, taken from recess period practice, speed and accuracy instructions.[14]

[13] Those of our learners used chiefly for introspection have been called 'observers.'

[14] It is to be regretted that the majority of our introspections are taken from recess period practice. This state of affairs is made necessary in the early part of the learning, since it is not wise to accumulate circuits at a time when so much occurs in the experience of the subject and when each circuit requires so much time for its completion.

Obs. 3 (1st day of practice). "As soon as I heard the signal I proceeded to follow the arrow." (The arrow indicated the direction to be followed at the beginning of the circuit). "Then my stylus struck the niche up on the twelfth side. I did not know I was moving in that direction until I struck the side; I tried to push away but found I was pushing against the side.

I attempted two or three times to get away but could not; I thought the electric current must be holding the stylus against the side; I was aware of intensive strains in my arm and the whole affair was very unpleasant. Fnally I gave up and relaxed for a time. I again looked at the star and noted that my stylus had moved partly out of the niche during my relaxation. I attempted to get away, but drove the stylus back into the niche again. Then the muscles of my arm and shoulder tightened and, with a quick movement, I pulled the stylus out of the niche and down past the arrow. This movement carried me again into the niches on the first side."

Obs. 6. (1st day of practice). "I got into a difficulty as soon as I started; I tried to get out by moving first one way and then the other, but this did not help. I was then aware of strains in my hand and arm; these strains became more intense, the more I tried to get out. Finally I moved right out of the niche. I did not direct this last movement; I simply saw that I was moving in the right direction. After this movement, whenever I saw I was going in the right direction, I refrained from interfering with the movement. While the strains were present and I was attempting to get out of the niche, I was aware of the following in vocal-motor imagery: 'Go in the opposite direction to the way it seems.' But I found that this did not help, for I did not know how to go in the opposite direction, until the new movement came mechanically."

Obs. 2. (1st day of practice). "I was first aware of a keen visual fixation of the groove and of the tip of the stylus. Then I observed that I was in a niche; I pulled out mechanically. When the stylus was going in the right direction I simply let it go; whenever I got caught I tried to get the kinaesthetic feel of the movement in the right direction, but I could not initiate this new movement. I simply kept on the lookout for the successful movements when they came. On the sixth side I got into a difficulty; I turned away from the mirror and was aware of the strains in my arm. When I looked back I saw I was moving in the wrong direction; this movement was stopped mechanically. Then I was aware of moving in a direction at right angles to the wrong movement; this new movement was right. When I am in a difficulty I am always aware of a focal visual fixation of the sides of the star and of the tip of the stylus."

Many difficulties of the same sort as those we have just described persist for many circuits of the star; the behavior is much the same as shown above, although the experiences eventually become short and fleeting. The following are illustrations of these difficulties which come up in later circuits of the star.

Obs. 1. (10th circuit). "When I get into a difficulty I am aware of manual-motor strains; the forward movement, or the one which is leading me into difficulty, is stopped mechanically. I become aware of a clear visual fixation of the groove, and then the successful movement comes. I find no important difference between my present method of meeting a difficulty and the method which I employed at the outset of the learning. The only difference I am able to observe is that the successful movement comes sooner, I do not wait so long. Formerly, in case of difficulty, the new movements were very short and I stopped momentarily after each one." (Do you pre-image your way out?) "No; I never do on the difficult sides; I simply look at the sides and sometimes move my eyes along the path, and the appropriate movement comes. The corners are most difficult for me, and, at these points, I am aware of clearly fixating the groove. On approaching a corner I immediately slow down the last movement, and the new movement along the next side comes mechanically."

Obs. 7 (2nd circuit). "When I get into a difficulty I move much more slowly; I am not aware of any conscious processes directing my movements. I have a clear visual awareness of the groove and the tip of the stylus. When I get out of the difficulty I am aware of visually fixating the plug ahead; this is followed by a rather quick movement down the groove."

Obs. 4. (5th circuit). "I cannot describe clearly my method of guiding the stylus in the difficult places. I seem to stand by as a spectator and watch my hand doing it. When I am on the fourth side, which is the most difficult side for me, I am aware only of clearly fixating the edge of the groove. There are intensive strains in my arm and hand, and the whole arm seems to be stiff and to work as a unit."

Obs. 7. (10th circuit). "At times I am aware of making the movement of tracing a difficult side with muscles in arm and hand somewhat relaxed; at such times the movements come easily. By this I mean that the strains in my arm are much less intense and the movements are faster. This is the only change I am able to observe which has taken place on the difficult sides since my first circuit."

Our introspections clearly show that the learning begins by trial and error and continues throughout on this basis. The only change which takes place through practice is the partly relaxed condition of the muscles as described in the foregoing introspection. We have no evidence of any other factors in the current control of the stylus than visual perception, followed by muscular strain which may be unpleasant. One of the strongest confirmations of this point is the fact that our observers, throughout the course of the learning, insist that the control comes entirely

through the close visual fixation of the groove immediately ahead of the stylus point.

Obs. 3. (2nd circuit). "Most of my movements on the difficult sides are of the zigzag sort. The sight of a niche ahead serves to stop the movement mechanically." (5th circuit.) "All the wrong movements are inhibited by a downward pressure of the stylus; I simply see the stylus approaching the edge of the groove and I press down reflexly. If I watch the stylus tip and the groove carefully, my stylus moves down the center of the path and does not take a zigzag course as it does when I am not attending closely to the visual situation; formerly I zigzagged from side to side and frequently came into contact with the edge. Now I keep my eyes fixed throughout on the edges of the groove."

Obs. 4. (2nd Circuit). "I stop all the unsuccessful movements mechanically. I simply concentrate my visual attention and watch the groove. When I am watching carefully, the unsuccessful movements are inhibited before they touch the edge of the groove. There are intensive strains in my arm when these movements are inhibited, and I am aware of having pressed down on the stylus when the movement was stopped. When I am aware of being in a niche, I pull out of the niche reflexly."

Obs. 6. (5th circuit). "I inhibited all erroneous movements by pressing down on the stylus; the sight of the stylus moving toward the edge is followed by this reflex pressing down. I simply do it as mechanically as I wink my eyes when something is flying toward them."

Obs. 2. (5th circuit). "I check all the false movements mechanically. I clearly fixate the groove when the errors come, and this is followed by a tightening of the muscles which results in a stiffening of the forearm."

Obs. 9. (5th circuit). "All forward movements in the wrong direction are stopped mechanically; I am aware simply of staring at the sides; then muscular tensions develop and I am aware of pressing down on the stylus when it nears the edge of the groove."

Throughout the above introspections, secured in recess period practice, it will be seen that the observer emphasizes the mechanical inhibition of the forward movement. This is characteristic of recess period practice, speed and accuracy instruction, under conditions when the subject is selecting either speed or accuracy—in this case the latter—but cannot improve in both elements of the learning simultaneously, see Fig. 6, p. 16. In later series practice tracings, the mechanical, jerky movements

give way to steady, flowing movements and the observer is unaware of the abrupt inhibition of forward movements.

b. *Difficult and Easy Sides.*—As was pointed out above, the sides of the star readily fall into two classes,—difficult and easy. The difficult sides may or may not be those which involve many errors or contacts between the stylus and the edge of the path. A careful comparison of the subjective estimate on the comparative difficulty of the sides with the learning efficiency thereon, fails to reveal the fact that the basis of the estimate of difficulty is the number of errors made.[15] Introspective analysis shows clearly that difficulty always involves the presence of muscular strains or tensions. The sides which are invariably easy are the ones parallel to the median plane of the body, where the muscular tensions are much less and where the movements are longer and more sweeping. A side which is found to be difficult is always a side where improvement is taking place; an easy side is, in the large majority of cases, one where little of importance takes place and where no improvement is being made. The oblique sides are often reported to be easy; and when so reported the error and time records show no improvement. The following typical introspections, taken from series practice, speed and accuracy instructions, illustrate the foregoing points:

Obs. 2. (3rd circuit.) "On the difficult sides today it seemed that there was a tendency for my hand to move in the wrong direction; and there was a very noticeable sensation of strain when these movements were inhibited. At these places where strains occurred I am aware always of fixating focally the edges of the grooves. Sometimes I find these difficult places somewhat unpleasant. Usually, in the difficult places, I stop, make tiny excursions, and when the correct movement comes it is allowed to complete itself."

Obs. 2. (5th circuit). "On the seventh side, which is the most difficult one for me, I was aware of intensive muscular strains in my hand and arm; these strains were especially strong when I was making the zigzag movements. The strains in my arm came after I entered the groove on the difficult side; the situation seemed to be clearly objective on this side. I was aware of fixating the tip of the stylus and the edges of the groove most of the time." (The tracing of this side showed great improvement of this circuit).

[15] To facilitate the matter of determining the efficiency on the difficult and easy sides, apparatus *I* was modified by placing copper plugs in the path at each vertex; with this variant we obtained the time and error data for the tracing of each side.

Obs. 2. (7th circuit). "The seventh side was difficult for me today. There was great effort there to avoid errors; this effort consisted in a very slow movement when I found myself near the sides. When the new movement came, I speeded up automatically if it went in the right direction; if the movement went in the wrong direction, I was first aware of stopping, and then of strains in my arm. There were no mental processes between the seeing that I was going wrong, the stopping of the bad movement, and the change of the new movement. The whole tracing on this side was slightly unpleasant." (The objective records show that the tracing on this side has improved in both time and errors).

Obs. 2. (8th circuit). "On the seventh side today I was aware of making little movements and also of visually fixating the tip of the stylus. This has become my procedure on all difficult sides. I do not set out with any purpose to do this; I merely am aware of sensations of muscular strain and these were slightly unpleasant." (The tracing on this side shows improvement in this circuit).

Obs. 2. (9th circuit.) "The seventh side was easy today. I think I went faster there; before I had completed this side my eye had gone to the next, and I was aware of muscular tensions in anticipation of it. There was a slight relaxation of the muscles of my arm on the seventh side and I did not fixate the edges of the groove so carefully as I do at times." (The seventh side today shows an improvement in time and an increase in the number of errors).

Obs. 3. (3rd circuit). "The sight of the grooves on the sixth side seemed to slow the forward movement of my stylus. I had automatically speeded up on the fifth side and was going at a good speed when I became aware of the sixth side. The visual perceptions of it seemed to turn my stylus reflexly into the groove of the sixth side. The first movement I made was wrong; my visual perception served to inhibit this movement. I was then aware of little short movements which were rather aimless; then a successful movement came and I allowed it to complete itself. There were intensive strains in my arm on this side and the tracing was somewhat unpleasant. I carefully watched the edges of the groove." (The tracing today showed great improvement).

Obs. 3. (4th circuit). "I had difficulty with the sixth side. I saw the stylus was about to touch the edge; this served to stop me reflexly. My stylus moved to either side in a zigzag fashion and was stopped when I was about to touch the edge. I was then aware of a movement down the middle of the path,—which seemed to come of itself. This movement carried me along the side. There were intense strains in my hand and arm, and the tracing was somewhat unpleasant." (The tracing shows improvement in both time and errors).

Obs. 3. (10th circuit). "On the sixth side I was aware of some short

movements. However, I was not aware of very much strain during the circuit of the sixth side. The eighth, ninth, and tenth sides were also very easy for me today." (The sixth, seventh, eighth, ninth and tenth sides all show a loss in accuracy during this circuit).

Obs. 6. (8th circuit). "I do not anticipate the difficulty of a side until I begin to trace it, but I am always aware of the difficulty of a side after I pass it; the basis of the difficulty of the sides seems to be the muscular strains that were there."

The reader should note that the stylus always pursues a zigzag course in the earlier tracings of a difficult side. This course, as our objective and physiological analysis will show, is modified by the effect of the recess intervals into a course which is practically a straight line extending down the middle of the path. Thus it is seen that, in the earlier tracings, the forward movement of the stylus is accomplished by means of alternate right and left lateral[16] movements with a general forward trend; while in the later tracings, the forward movement is secured by means of a simultaneous functioning of those muscles concerned with the lateral movements, together with certain other muscles which produce the forward movement. It is this simultaneous functioning, or functioning in close succession,[17] of opposed musculature which gives rise to the 'stiff' arm, reported by all our observers attempting to secure accuracy under the conditions of recess period practice; and in our opinion, it is the 'stiff' arm which affords the physiological basis for the feeling of difficulty, always somewhat unpleasant.

The unpleasant muscular tensions occurring on a difficult side are followed by a marked relaxation, when the tracing of the side is completed; especially is this the case, when the difficult side is followed by an easy side. And this relaxation is the physiological basis of the pleasure which results from the successful tracing of a difficult side. This 'satisfyingness,' as Thorndike (49) would

[16] By lateral movement, we mean any deviation of the zigzag movements away from the general trend of the forward movement. Thus, if the general trend of the forward movement is toward the right, then up or down deviations from this forward trend would be termed lateral movements.

[17] The reader is referred to the following section for a detailed analysis of the physiological aspect of the problem.

term it, is, in our opinion, nothing more than an indicator pointing to the fact that the tensions and strains on the difficult side are ended and thus they mark the transition from one physiological state, tension, to another state, relaxation.

c. *The Influence of Satisfyingness upon Improvement.*—Our introspections show that the successful tracing of a difficult side is very often followed by a feeling of satisfaction.[18] This feeling, in our opinion, results from the muscular relaxation which attends the completion of a difficult tracing and has no effect whatsoever upon the learning; while Thorndike makes the feeling of satisfyingness of prime importance in the selection of the successful responses. The following introspections will show the occurrence of this affective state in tracing the star:

Obs. 3. (5th circuit). "As I approached the third side I had a faint auditory-motor *Aufgabe* 'go slowly around corner.' This was carried out and I moved around the corner in a straight line,—the usual zigzag course of the stylus was absent this time, which gave me a definite feeling of pleasure. On the third side I came near touching the side; this was followed by very slow movements which led me along the side without any errors, and was very pleasant."

Obs. 2. (4th circuit). "On side one the first move the stylus made happened to be the correct one. There was no tendency to swerve from side to side and I completed this side without an error; this was followed by a marked relaxation and a feeling of pleasantness."

We are quite unable to see that this satisfyingness which follows the satisfactory tracing of a difficult side, or the making of a successful stroke, can in any way influence the reappearance in later practice of those responses preceding or concomitant with the affective state. That the movements followed by relaxation (satisfyingness) will often be repeated more or less in their original form is assured by the fact that they were fully completed,—a state of affairs further attested by the fact that they call forth no further strains or effort in the reflective memory of the observer during his act of introspection.[19]

[18] The reader is referred to Thorndike's Original Nature of Man, Educational Psychology, Vol. I, for a good account of his view of the part played by the feeling of satisfaction in learning.

[19] Joseph Peterson, in a recent article, (35) has ably supported this same contention; also John B. Watson, Behavior, Henry Holt, New York, 1914,

It is the progressive modification of movements that conditions improvement in this investigation, not the 'stamping in' of successful responses, as in Thorndike's view. This is clearly shown in our physiological analysis of the learning. On those sides of the star (the vertical sides) where every movement is followed by the feeling of satisfyingness, practically no improvement takes place from the first circuit to the end of practice; the improvement occurs on the difficult, oblique sides.

In the earlier stage of the learning the highest rate of improvement we have observed in this problem has occurred where the subject is given accuracy instructions and recess period practice of one circuit per day, or with recess of twenty-four hours. Under such conditions the improvement comes about wholly through the resolution of a zigzag course of the stylus into a straight course down the middle of the groove. We have already tentatively shown in our summary of the learning curve, which will be supplemented by other material in a later section, that the recess period is responsible for this change in the course of the stylus. The recess period resolves a zigzag course with marked lateral movements into a smooth course with no lateral movements; from which effect there results often a marked improvement in speed and accuracy in the first repetition after the recess.

From such evidence it is readily seen that no selecting agent, such as the 'satisfyingness of a response,' is operating to 'select out' the successful responses made in a series of random movements—the basis of the Thorndike view, since the successful responses, straight course of stylus, did not occur at all in the tracing before the recess. An entirely new movement has come about, the result, as we shall show in the following section, of the simultaneous functioning of opposed muscles which, prior to the recess, functioned in succession. The learning takes place without selection and no selector is needed,—the recess period alone being adequate to produce such physiological changes as will lead to the improvement.[20]

Chap. VII, points out that the known laws of frequency, recency, etc., are quite adequate for fixing arcs in habit formation.

[20]Thorndike's view has been formulated wholly to fit the case of improve-

D. Typical Behavior under Instructions

We have already touched upon many of the features characteristic of an observer's behavior when avoiding errors, or when speeding up; we shall now go into some detail in an analysis of this behavior. Observers were given the two types of instructions at various stages of the learning, one type insisting upon speed, and the other upon accuracy. Introspections were secured from all of our observers working under these two types of instruction; but we made a special attempt to obtain a more accurate analysis from two of our observers, 2 and 9, who possessed a high degree of skill in introspecting, and we shall select our citations largely from their introspections.

a. *Behavior under "Accuracy" Instructions.*—The most characteristic feature of the learner's behavior under these instructions is his clear fixation of the edges of the groove. When instructed to avoid errors, he immediately begins to fixate the groove; and, during the fore-period, becomes aware of strain sensations and of incipient movements along the first side of the star. (We have called the fore-period that period of time which intervenes between the instructions and the beginning of the tracing of the circuit). The fore-period is characterized by a great variety of imaginal and affective content, which, however, disappears when the movements of tracing are in progress; there remains merely the clear visual fixation of the edges of the groove, and the strain sensations from the muscular responses to the objective situation, with a high degree of affective toning. The following introspections will illustrate this point.

Obs. 9. (4th circuit.) Fore-period: "On hearing the instructions I was aware of a keen physical alertness; and before I looked at the star there was a mass of visual imagery; prominent among these visual images was that of a record with arrow marks upon it. Then I perceived the star; my eyes rested upon the starting-point for an instant, then moved down the side.

ment after many repetitions of an act, which is clearly evidenced by his extreme emphasis upon 'use' in the formation of bonds. His strictures against Book and Swift (Educ. Psychology, Vol. II, p. 314) furnish still further evidence that he is unable to deal sympathetically with those who would put any improvement upon the basis of cerebral growth or 'automatic organization of bonds.'

The motor side of consciousness became intensive, and I was aware of an incipient tendency to move my hand along the groove; this consisted of kinaesthetic sensations in my arm and shoulder. The muscles were tensely contracted in the shoulder and upper forearm." *Beginning of a Circuit:* "Your signal, together with the readiness above referred to, was the immediate antecedent to my starting off. At first there was just a visual percept of the movement; then I glanced at the plug ahead and was aware of a movement around the corner. As I turned the corner I was aware of clearly fixating the niches, my line of regard being just in front of the tip of the stylus. When I passed the corner and came to the vertical side, attention shifted to the muscles of my arm; I was aware here of the ease and lack of strain in the movements and was also aware of speeding up reflexly. My visual line of regard was much farther ahead of the stylus when I was moving faster. When I came to the eighth side, I perceived the whole side at one glance; this was an easy side and I made it in one stroke. On the ninth side I was aware of a dull pain in my shoulder and arm as the stylus moved along; I fixated the niches of the side and my control seemed to come entirely from this visual perception." (5th circuit, no recess period between 4 and 5). "This circuit was much less difficult than the former; I gripped the stylus less tightly, moved faster, and my visual attention was directed much farther down the groove."

Obs. 9. (6th circuit, after recess). *Fore-period;* "I had vocal-motor images: "Reduce errors.' Then I was aware of clearly perceiving the groove; this was followed by gripping my stylus. There was an increasing tension in my arm and shoulder." *Beginning of the Circuit:* "On the signal I was aware of a keen visual fixation of the edges of the groove, and the movement of the stylus down the groove. I also noted a sense of heaviness in my muscles as I approached the corner; this seemed to be chiefly a dragging sensation in my arm and shoulder, and was always a characteristic of my accuracy *Aufgabe.* At the corner there was also concentrated visual attention on the niches. As I proceeded around the star I was aware that my visual line of regard was progressing farther and farther from the tip of the stylus; I was also aware of moving faster at such times. This awareness of speed was followed by an increased pressure on the stylus, which reduced my speed."

Obs. 9. (7th circuit, no recess between 6 and 7). "In this circuit there was much less tension in my muscles and my visual line of regard remained much farther ahead of my stylus than in the first circuit. I was aware of moving faster and faster as I proceeded. At times I was aware of a visual perception which seemed to include the whole star; and at such times my speed was very marked. After getting caught in a niche I was aware of the *Aufgabe* to decrease my errors; this consisted of a memory image of rapid movement in previous circuits with visual and kinaesthetic images of errors. All of this developed into a keen concentration on the groove immediately in front of my pencil point; there was also an awareness of increased pressure on the stylus, and a stiffness in the muscles of the arm and shoulder."

In the above introspections we have an unusually clear account of the gradual development of speed under series practice conditions, which, in an earlier section of this paper, was shown to take place when circuits are accumulated without intervening recess. (See Figs. 2 and 3.) A striking characteristic of the development of speed through series practice is the fact that visual attention spreads over larger and larger areas of the star. In recess period practice the visual perception is narrowed down to the tip of the stylus and the edge of the groove on either side of the stylus. Another significant point in the above introspections is this observer's clear analysis of his accuracy *Aufgabe,* which consists simply of a close visual fixation of the objective situation, with pronounced muscular strains in the arm and upper trunk. The followmig introspection is significant because it reveals the extreme emphasis upon accuracy after a long recess.

Obs. 9. (8th circuit, two weeks after the foregoing circuit). *Fore-period:* "I was aware of vocal-motor imagery: 'Decrease error.' Then I had a visual image of seeing my hand go around the groove; I was aware of a gradually increasing tension in my arm and shoulder, and became impatient to begin. There were incipient movements of beginning." *Beginning the circuit:* "As I began there was a very close concentration of visual attention on the center of the grove; the movement was slow and there was a marked muscular strain; at the corner I gripped the stylus tightly and watched the niches carefully. On the difficult sides in this circuit I was aware of great muscular strains; it seemed as though I were pushing against a wall, in fact, I actually visualized a wall at such times. On the eighth side I was caught in a niche, this was followed by an auditory image, 'accuracy,' in terms of your voice; then I was aware of the return of the accuracy *Aufgabe* which I have already described."

The following introspection furnishes a more complete analysis of this observer's accuracy *Aufgabe.* The observer had been asked to seat himself before the star and then to wait for the instructions.

Obs. 9. (9th circuit). "When I sat down before the star I was aware of a gradually increasing adjustment to the total situation. This consisted of muscular strains of sitting up straighter in my chair, glances at the star, and at times a focal visualization of the starting-point. Then after your instructions I repeated them to myself in vocal-motor imagery." *Beginning of Circuit:* "On the signal there was a sudden rise in the focal intensity of the visual perception. There was no kinaesthetic image of movement; I was simply aware of moving down the groove with my eyes fixed on the tip of

the stylus and upon the edges of the groove on either side. I was often aware of the instructions in auditory imagery, which was followed by a clear visual awareness of the groove at the tip of my stylus, and then I was aware of strains in my arm and shoulder,—the arm seems to be quite stiff. All this constitutes my accuracy *Aufgabe*."

The reader will observe that throughout all the introspections quoted, there is one element of control,—the clear visual perception of that portion of the groove which lies immediately in front of the stylus. As speed develops, the line of visual regard moves away from the stylus and the visual perception seems to be spread out; when a difficult place is encountered, the visual line of regard returns to the tip of the stylus. This is often followed by an imaginal representation of the instructions. All of our introspections show, however, that this representation of the instructions does not appear in advance of the strain sensations which are characteristic of the accuracy *Aufgabe*. In the vast majority of our introspections, the verbal instructions do not appear after the tracing of the circuit has begun.

We shall now quote a typical introspection of Observer 2. The practice here was under the accuracy instructions.

Obs. 2. (3rd circuit). *Fore-period:* "I was first aware of a remembrance of the last circuit. I had a visual image of holding my stylus in a slanting position; I saw the contact on the plug and the electric spark. This was followed by an adjustment of the stylus in which I raised it to a perpendicular position." *Beginning of Circuit:* "On a signal I started out mechanically; the first movement happened to be right. I was aware of intense and shallow breathing; there was a tension about the face, jaws, and a gritting of the teeth as I approached the corner; this was concomitant with a clear visual awareness of the corner. Throughout this whole circuit I clearly perceived the groove just in front of my stylus. Sometimes there were movements in the wrong direction; these were inhibited mechanically. When I was not under strain I noted that the speed of my movement had increased; when I was aware of speed my line of visual regard was always far ahead of the tip of the stylus."

b. *Speed and Accuracy Instructions.*—Under this type of instructions we have a somewhat different behavior, yet one that is identical with that which obtains in the speeding-up places under the *accuracy* instructions. In the *speed and accuracy* instructions the observers were instructed to go around the star as fast as possible and avoid errors as far as possible. It should be noted

in these introspections that we have an occasional reference to the use of kinaesthetic control image.

In the following introspection the observer was attempting to secure speed and accuracy under recess period conditions; this leads to an alternation between the speed and accuracy attitudes and involves an extraordinary amount of muscular strain and feeling of effort on the part of the observer.

Obs. 2. (15th circuit). *Fore-period:* "When speed and accuracy instructions were given I was aware of clear kinaesthetic strains in my shoulder, and there was a very strong tendency to start before the signal came. There was great muscular tension throughout my body." *Beginning of Circuit:* "I began with my attention on the kinaesthetic situation. There were strains in my arm, shoulder and back. I had a kinaesthetic image of movement down the first side; this was followed by the movement. I was aware, as I proceeded, of increasing muscular strains: these were localized in the muscles of the back and arms. There was a rapid increase in the rate of the heart beat. I made many errors and was caught a number of times in the niches; I went much more slowly after being caught. On the whole, the last half of the star was traced more slowly than the first, and my attention was more on the niches and the general visual situation, and less on the kinaesthetic elements. When I reached the starting place I observed that I had gone around the star the wrong way."

In the above introspection it will be observed that, during practice in speed, the learner's attention shifts from the visual to the kinaesthetic situation; this we observed to be the case in the accuracy practice whenever speed was developed at the easy places; after the errors were made, however, when accuracy became necessary, attention shifted back to the objective situation. It should also be noted that the learner began with a kinaesthetic control image which is the first to be reported so far. The observer also traced the star the wrong way; that is, he began with the twelfth side and ended with the first side. (If the reader will turn to Fig. 1, he will note that the twelfth side extends upward and is in the apparent direction of the first side; in other words, the mirror image simply reverses the relative position of the twelfth and first sides).

The two following quotations are presented here because of the light they throw upon the working of a plan of procedure. These two were chosen from a host of others, all of which bear

out the same points, namely,—that no conscious use of a plan or device is of value in tracing the star, except the plan of tracing deliberately. The experienced subject starts out slowly and moves deliberately, even though he be instructed to trace at his highest speed; this we have called the *discounting* of the speed instructions. However, this discounting of the instructions occurs only when the subject is working under speed and accuracy instructions.

Obs. 9. (40th circuit). *Fore-period:* "Before the instructions were given, I was engaged in working out a plan of procedure. I decided to hold the stylus vertically at all times and grip it tightly." *Beginning of Circuit:* "As soon as I heard the signal there was a rapid plunge along the first side. My eyes were fixed on the objective situation; the movements were very mechanical; there were strains in my arms and in the muscls of my shoulder and back. At times I speeded and at times I went very slowly. At the speed places my eyes were directed far ahead of the stylus; but at the difficult places I perceived clearly the tip of the stylus and the edges of the groove on either side. My stylus was caught a number of times during the circuit and I found that I was unable to make use of my plan of procedure. It seemed that the objective situation determined my reaction."

Obs. 2. (20th circuit, 5th circuit under the special caution to introspect her plan of procedure). *Fore-period:* "In this fore-period I was aware of working out a plan of procedure. I first had visual images of moving very rapidly around the star without touching the sides; then I had a visual image of getting caught. This was followed by intense unpleasantness and vocal-motor imagery, 'you had better go slowly at first.'" *Beginning of Circuit:* "On the signal, my visual attention narrowed down to the tip of the stylus and the groove. I started in with slow movements, but on the fifth side my visual attention moved ahead of the stylus and I was aware of speeding: the last half of the circuit was made at much higher speed." (Was your plan of procedure successful?) "Yes; this one was. I find now that when I begin slowly and attend to accuracy, I make higher speed than when I begin impulsively."

c. *Positive and Negative Instructions.*—An attempt was made to study the effect of positive and negative instructions upon the tracing of the star diagram by mirror image. Our quantitative data and introspective accounts furnish no support to Langfeld's (23) finding that only negative instructions suppress the control imagery. In truth, we find that under both positive and negative instructions all imaginal processes are absent *during the tracing.* When the subject reaches an easy place on the diagram he reflexly

increases his speed of movement and may report the presence of imaginal processes at such times. The difficulty encountered in tracing a side determines whether consciousness must deal focally with the objective situation, or be left free to entertain imaginal processes. Whether the subject is instructed to "avoid touching the sides" or "go down the middle of the path," the quantitative results were the same in our experiment.

In a number of trial tests we employed the Stoelting tracing board used by Langfeld, and our results were able to show that the quantitative findings secured by him could be rendered more decisive, and be clearly explained, by controlling the recess period, which Langfeld fails wholly to do.

E. The Question of Control Imagery

We were surprised by the lack of control imagery in our introspections. Our observers had invariably reported an abundance of imagery in the fore-period; but this imagery appears to drop out during the tracing, especially so under accuracy instructions. In isolated cases our learners reported that a manual-motor-image was present before they began to make a rapid stroke down an easy side, but that this image dropped out during the course of the tracing. It occurred to us that the control might possibly be furnished by the visual perception in cases where the circuit was traced slowly under accuracy *Aufgabe,* and that a kinaesthetic or manual-motor image[21] might be the means of control in cases of high rates of speed. In order to test this conjecture we arranged the following series of experiments:

a. In a first experiment, Observer 5, who was about to begin her fifth circuit of the star, was instructed to begin with a rapid movement along the first side. It was thought that if the kinaes-

[21] Throughout our analysis we have considered that the kinaesthetic image of making a movement is the same as the manual-motor image. In both cases, our observers have always found a visual component, i.e., in a kinaesthetic image of making a movement down a groove, the 'down the groove' meaning is carried by a visual image of the groove. Whenever we have desired to keep clearly before the reader the visual and the kinaesthetic components, we have resorted to the use of hyphenated words, visual-kinaesthetic or visual-manual-motor, in describing the imagery.

thetic image should appear at all during the tracing of a side of the star, it would tend to appear under such instructions. A quotation from her introspection follows:

"I was first aware of my *Aufgabe* in auditory-vocal-motor imagery: 'hurry and make no mistakes.' Then I began the first movement with a quick manual-motor image of movement down the first side of the star. I was dismayed when I saw my hand going along the twelfth side instead of the first side. I stopped the movement and went slowly along the first side, but this time I had no image of the movement."

Seven days later this observer was given the same instructions and her introspection reveals precisely the same state of affairs. This situation, together with the introspection of Obs. 2 on her fifteenth circuit, as above noted, was sufficient to lead us to doubt the ability of the kinaesthetic image to function as a mode of control in this problem.

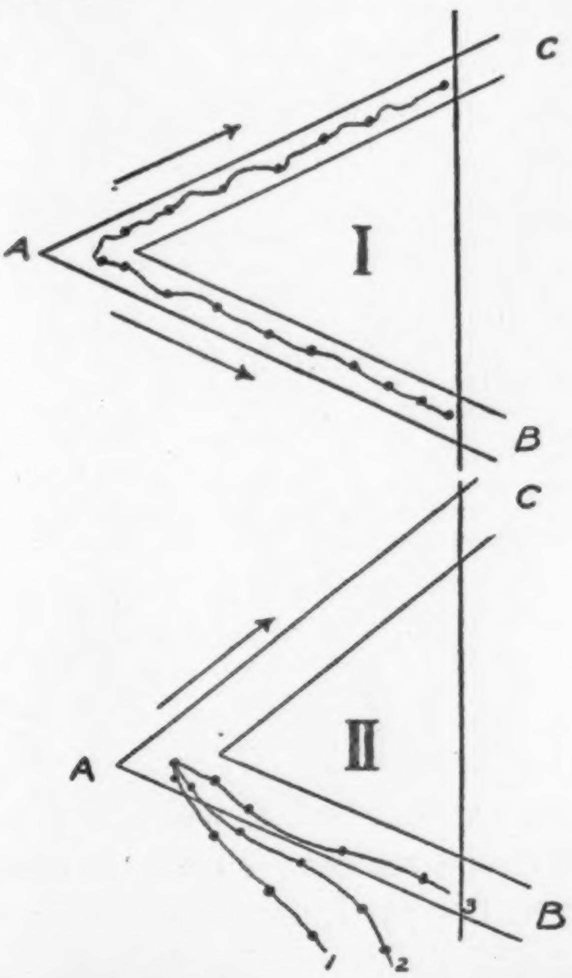

FIG. 9. An exact copy of the results of an experiment performed with Subject No. 9 upon apparatus II. In *I* the subject traced the path *AB* slowly and deliberately, and likewise the path *AC;* in *II* the subject was instructed to trace the side *AC* indicated by the arrow, with one rapid stroke. In the three attempts at tracing in *II,* the subject traces in the apparent direction of the path *AC.* The stations on the tracing line indicate the time in fifths of a second.

b. To test the matter more completely, we added another special experiment, which was arranged as follows: Two sheets of blank paper were pinned together and a sheet of carbon paper was inserted between them. A diagram in the form of a simple acute angle was drawn on the upper sheet, its carbon impression being recorded on the sheet below. (Fig. 9). This diagram was placed upon the tapping machine, Apparatus II, so that the sides of the angle were in exactly the same position as the first and twelfth sides of the star. Observer 9 was chosen as observer; since this observer had made about one hundred circuits of the star prior to this test. The time-recorder was set at five beats per second. The observer was asked to start at *A* and trace the side *AB,* Fig. 9, I, and to keep directly in the middle of the path and move as fast as possible; this was our speed and accuracy instructions. His introspections revealed the presence of no control imagery. He was then asked to trace the side *AC* under the same instructions; and control imagery did not appear here.

In a second test, Fig. 9, II, the observer was asked to trace the side *AC.* keeping as nearly as possible on the line, but 'to make the tracing with one rapid movement.' The observer was aware of a kinaesthetic control image in this tracing; his stroke, however, was on the side *AB* and is shown in Fig. 9. He was asked to repeat the stroke a number of times. The time of each stroke is indicated on the path of the stylus, (Fig. 9), and it should be noted that the fast strokes move out on the apparent side and not on the side designated.

The detailed introspections of this observer reveal the fact that during the fore-period of the one-rapid-stroke test the observer was repeatedly conscious of manual-motor images of moving the stylus down the appropriate side. He assured us that these images could be reproduced at will and he was confident they were adequate to control the movement. However, when the stroke was made according to the particular instructions which were best suited to the production of the image,—one rapid-stroke,—he traced the apparent side of the angle rather than the true side, as in the case of the two former experiments. (The reader should note that in the mirror image the side *AB* is in the position of the

side *AC* of the direct vision situation). On the repetition of this test, however, the subject traced the appropriate side slowly and deliberately, without the slightest trace of manual-motor imagery and with complete awareness that the control came from the visual situation.

Another phase of this observer's analysis of his behavior under instructions lies in the behavior of the visual attention. When tracing slowly and with deliberation, his attention is directed focally to the visual details of the line to be traced; but when he reacts under the one-rapid-stroke instructions, his visual perception consists merely of a general awareness of the direction of the path; and, in addition, there is a marked consciousness of the motor situation, involving muscular strains in the shoulder and arm. This latter is precisely the state of affairs we found in the speed tracings on the star, i.e., the definite awareness of the *motor* situation alternating with, and never concomitant with, the focal visual awareness of the objective details.

When the objective situation was removed and this observer was asked to reproduce the objective and subjective situations in imaginal terms, his analysis reveals that the essential character of the visual component is a certain lack of details,—the line to be traced is imaged as a whole; and, he introspects that the awareness of the motor component follows directly upon the awareness of the visual element. The observer is further convinced that the imaginal state of affairs in this instance is the exact replica of that which obtains in the fore-period when he is instructed to make the tracing of the line in one-rapid-stroke.[22]

Summarizing our findings in the case of the above observer, we find (1) he is able to follow the path designated by moving slowly, with clear visual attention upon the objective details, but is unaware of imaginal processes; (2) he is able to trace the

[22] It should be noted here that the trained subject is able to trace the proper line with one-rapid-stroke by delaying the stroke through pressure on the stylus until the eye has inspected the details of the line. This delay we have called the 'initial delay' and it is worthy of note that when the subject resorts to the initial delay he is unaware of imaginal processes but is conscious, with an unusual degree of clearness, of the details of the objective situation.

proper line with one rapid stroke, provided he delays the start—our initial delay—by pressing downward on the stylus until he has inspected the visual details of the path, but is unaware of imaginal processes; (3) he traces the apparent line,—thus falling back to the first stroke he employed when he began mirror tracing,—when guided by a visual-manual-motor image, or when the visual objective situation is diffuse or general.

From the foregoing, we are led to the conclusion that in the case of this subject the visual objective situation—detailed visual awareness of line and visual awareness of the stylus moving along the line—is the sole means of control.

c. To further test the problem of imaginal control, an advanced class of twenty students in experimental psychology in the University of Utah was given the following experiment. A diagram similar to the one shown in Fig. 9 was printed on cards. The students learned to trace the line *AB* by repeated practice, a new card being used for each tracing. When each student had traced the design fifty times, and thus, for all practical purposes, had reached his limit of improvement, he was asked to draw the diagram, which he had not seen for twenty-four hours, and indicate the line *AB* which he had been tracing. Each student was required to furnish an introspective account of his procedure in making the drawing.

Seventeen of the twenty students drew the line in the position of *AC*, and the entire twenty were convinced that the mental basis for constructing the diagram was the visual image of the path, combined with the manual-motor image of making the movements, the manual-motor image being the stronger component. If this manual-motor image gives no adequate basis for correctly locating the path that has been repeatedly traced, it is inconceivable that it can function to control the movement of tracing in the original situation.

d. A careful examination of all of our introspective data secured from our nine trained observers reveals the fact that control, or antecedent, imagery is almost completely lacking in this experiment. By control, or antecedent, imagery, we mean that imagery of a movement which just precedes, in point of time,

the execution of the movement. *Observer No. 1,* who has made over one hundred circuits of Apparatus I, under all varieties of conditions as to recess periods and instructions, was not aware of a single antecedent image during the entire practice. This observer is of a decidedly motor type and is highly trained in introspection. *Observer No. 2* reported two antecedent images during twenty-five circuits and both of these occurred during periods of partial relaxation or fore-periods preceding difficult portions of the star. *Observer No. 3* reported three antecedent images during twenty circuits of the star. *Observer No. 4* was not aware of antecedent imagery in two hundred circuits. *Observer No. 5* was quite frequently aware of what seemed to be antecedent imagery; this was also the case with *Observer No. 6. Observer No. 7* was not aware of antecedent imagery in making over one hundred circuits of the star. *Observer No. 8* reported no antecedent imagery. *Observer No. 9,* whose introspections have been used so largely in this paper, was aware of images of visual-kinaesthetic type only during fore-periods or during periods of relaxation; these, we have clearly shown, could not act as agents of control.

From the results secured in our special tests and from our general evidence, we are unable to see that control imagery can function in this problem. The fact is worthy of note that most of our observers expected to find control imagery; the fact that they did not do so became all the more interesting and important for our investigation. We have endeavored in this investigation to present all the available evidence fairly and impartially; but we have yet to find adequate evidence that a causal relation exists between the imaginal processes reported and the subsequent movements.[23]

[23] The writer, who has made more than one hundred circuits of the star, repeatedly sat as observer in the same experiment as was performed upon observer No. 9, above. The experimental findings and introspective results in our case are the same as reported for observer No. 9. The writer is able to get the clearest and most definite visual-kinaesthetic imagery of making the tracing with one rapid stroke; and yet, he cannot make the stroke unless the start is delayed by downward pressure on the stylus until the details of the path have been deliberately inspected visually; and in this case, there is not the slightest evidence or subjective feeling that the antecedent imagery was causally related to the movements. In fact, the writer is clearly aware, in such cases, that the imagery has no connection at all with the movements following the initial delay.

It is our belief that, in this problem, the illusion of movement produced by the mirror provides, for the problem of imaginal control, precisely the same analysis of the elements composing the complex, that the illusion in general does for the psychology of perception. In the former case it provides the most unmistakable evidence that the imagery antecedent to a movement cannot control the movement. The visual-kinaesthetic complex in imaginal terms is the precise replica of that objective visual and tracing situation in which a diffuse visual perception of a path to be traced is followed by a tracing in the apparent direction, rather than the true direction, of the path. The *sine qua non* of the visual imaginal situation,—since it is known to come quickly, and before the movement,—lies in its diffuseness. There is no new element in the imaginal situation which does not inhere in the perceptual situation; and thus, it cannot be a cause or a controlling agent for the movement.

Our conclusions for the introspective analysis may be summarized as follows: The behavior of the observer working under recess period practice with accuracy instructions, consists of a close visual fixation of the details of the path to be traced; slight muscular strains in the arm and shoulder develop because of the simultaneous functioning of opposed musculature,—the stiff arm of recess period practice; and there is an entire absence of imaginal processes of any sort. Under series practice conditions the visual attention comes to be spread out over a larger area of the star; the speed of tracing becomes greater, and the muscular tensions of the arm and shoulder in many cases becomes greater than for recess period practice.

Under speed and accuracy instructions, with recess period practice, the subject alternates between the accuracy attitude and the speed attitude. Under series practice, with speed and accuracy instructions, the observer maintains throughout the speed attitude which is made up of a diffuse, visual perception of the path to be traced, and fast movements, with the muscular strain much less than when the observer is attempting to secure speed in recess period practice.

In all accuracy practice the speed of the stylus is much the same

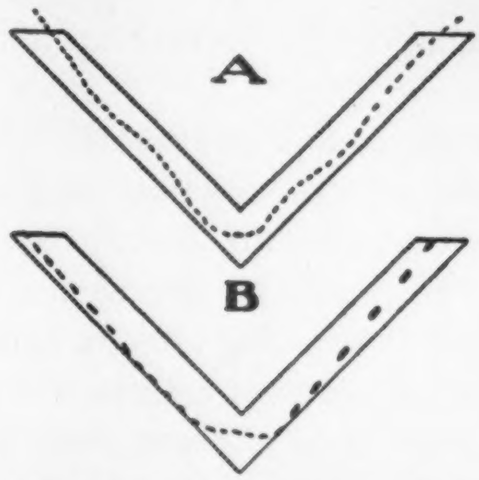

FIG. 10. An exact duplicate of a record made by Subject No. 3 upon apparatus IV. The tracing in *A* represents the work of the subject before he had attained a high degree of speed; the record in *B* was secured after the subject had acquired much skill and speed in tracing the diagram. The time is indicated in twenty-fifths of a second. In *A*, note that the time is spent equally on the two sides of the diagram; in *B*, where the subject is working under speed instructions, a great part of the time is spent on the first half of the diagram.

throughout the tracing; but in speed practice there are places of relaxation where the visual attention moves ahead to inspect the details of a difficult segment of the path; this is clearly shown by Fig. 10. During these periods of relaxation preceding the difficult tracings there may be, and often are, visual and manual-motor images of making the tracing, but these have been shown to be of no value in controlling the movements which follow them.

3. Objective and Physiological Analysis of the Learning

Throughout our account of the physiology of the learning we shall adopt the "neuromuscular unit" conception as advanced by Stiles (43). While we shall not go far as to accept the extreme position taken by Keith Lucas (25) in the matter of the fractional functioning of muscles, yet we do contend that a musculature must be conceived of as functioning at times fractionally, and at other times, as a whole. The physiological basis of this fractional functioning would seem to be the neuromuscular unit. In the eye-hand coordinations under investigations here, the neuromuscular unit may be conceived of as beginning at the cortical centers and

extending to and including the fibrillar units of the arm musculature.[24]

It is the central finding of this investigation that the number of efferent neuromuscular units to function simultaneously will depend upon certain conditions, the description and analysis of which constitute the chief aim of the writer in the following pages. The number of functioning afferent neural fibres extending from the retina to the cortical centers will be considered as constant; while the number of efferent fibres will be shown to vary.

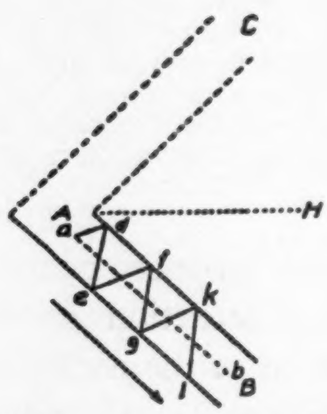

FIG. 11. A diagrammatic tracing of the first side of the star.

A. Function of the Recess Period

a. *Elimination of Zigzag Paths.*—We have already indicated that one aspect of the learning in this investigation takes place through the resolution of the zigzag course of the stylus into a smooth course: the recess period is the important factor in bringing about this resolution, since, without the recess, the only improvement possible is in the speed of the tracing. By referring

[24] The writer believes that it is physiologically correct and probably more exact to conceive of the neuromuscular unit beginning at the retina, rather than at the cerebrum. According to the former conception, the findings to be reported in this investigation, as to the varying number of muscular units to function under different conditions of practice, would be described as a variation in the number of neuromuscular units functioning from the retina to the arm under different conditions of practice.

This view is entirely compatible with the findings of this investigation. However, the point is a technical one and has not, to my knowledge, been presented by writers on the physiology of the nervous system; consequently, we shall follow the easier plan of describing a variation in the size of a functioning musculature as due to a variation in the number of neuromuscular units functioning from the cerebrum to the muscle.

to Fig. 11, it is clear that the smoothing of the zigzag path has come about through a fusion, simultaneous functioning, of the muscular elements entering into the successive movements, as in *ad* and *de*. That this fusion is not due to repetition, but wholly due to the recess period, may be seen by the course of the stylus in successive tracings which have not been separated by recess periods, Figs. 2, p. 13 and 12. If the recess periods are not inserted the zigzag course of the stylus is still retained.

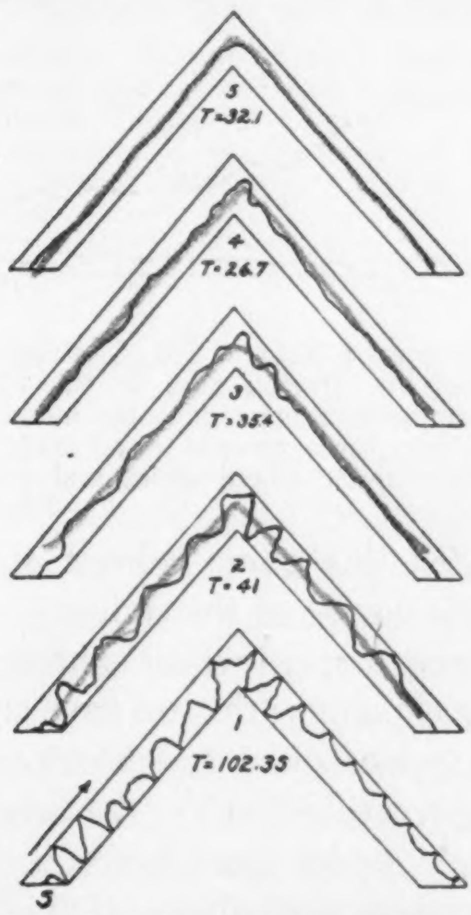

FIG. 12. An original tracing of a beginner, Subject No. 12, upon apparatus III. The circuits of the diagram were separated by ten minute recess intervals, excepting 3 and 4 which were in series. The time for the tracing of each circuit is indicated under the drawing.

b. *The Two Sources of Speed in the Learning.*—By referring to Fig. 13, it will be observed that this subject, who is tracing apparatus I, under recess period conditions with accuracy instructions, gains very much in speed of tracing, due to the elimination of the contacts against the edges of the path. The time lost in these contacts, and also that lost in the periods of arrest when the stylus is caught in the niches, is thus saved when the course of the stylus is straightened or smoothed out after the recess

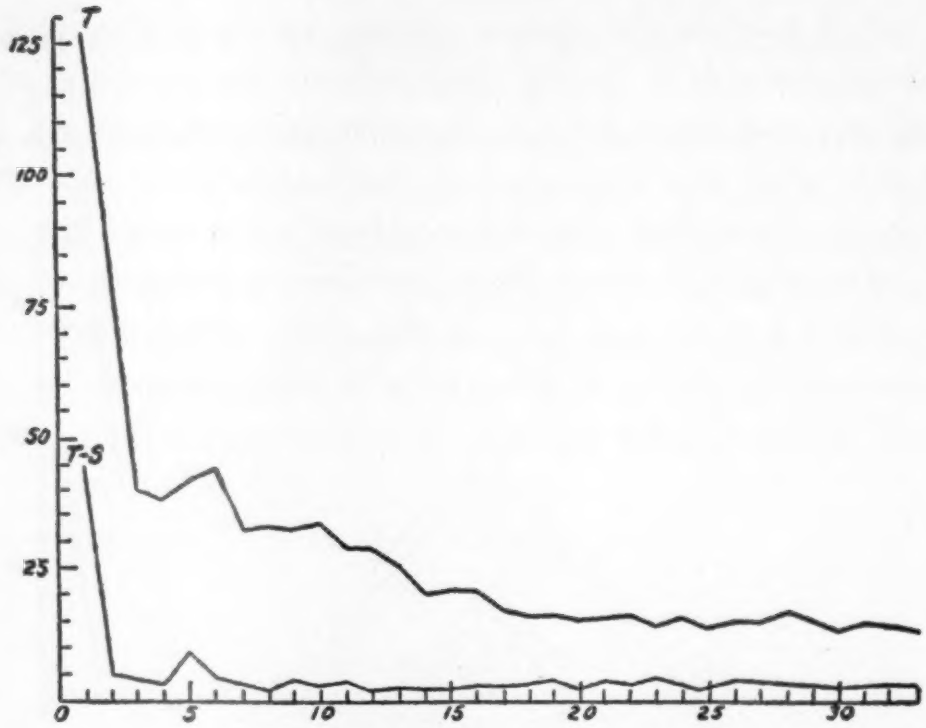

FIG. 13. A learning curve of Subject No. 8 which shows, in the upper curve, the total time for the tracing and, in the lower curve, the time actually spent with the stylus in contact with the metallic edges of the path upon apparatus I. The first three circuits were made under recess period practice and the remainder under mixed series and recess practice.

period; we have called this gain 'indirect speed' or the gain through smoothing the course of the stylus.

There is another type of speed which is brought about through series repetitions, Figs. 3 and 5; this we have styled the 'speed of facilitation.' In this type of speed the smooth course of the stylus does not vary during repetition, unless the speed be acquired too rapidly, as for example, under speed instructions, Fig. 16, p. 55. In the latter case the fusion and balance of the muscular elements is lost entirely and there results not the controlled movement down the middle of the path, but the successive movements which existed at an earlier stage of the learning.

In later pages it will be shown that, aside from indirect speed brought about through straightening the path, the recess period usually works to reduce the speed of movements which has been acquired through series practice. Series practice, through the speed of facilitation, will increase the speed of accurate movements whose accuracy has been built up through recess period practice.

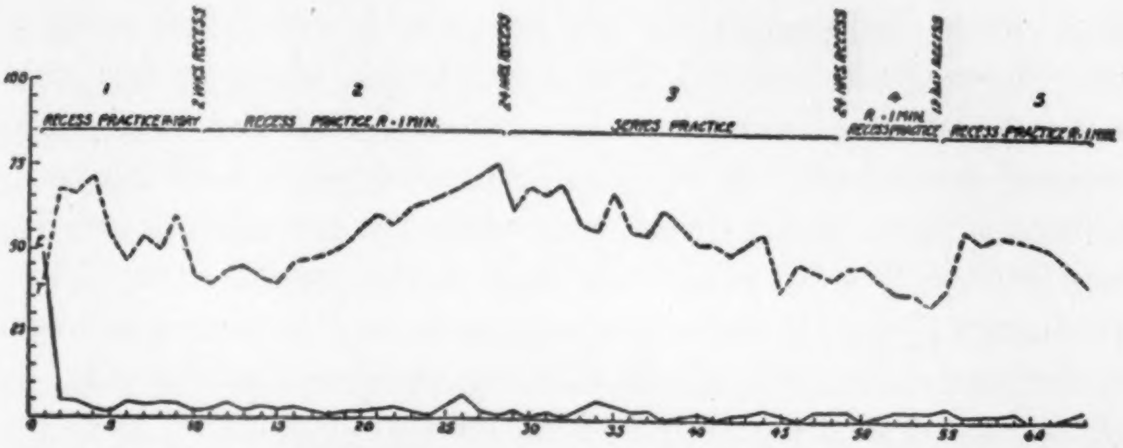

FIG. 14. Ordinate indicates time and errors; abscissa, successive circuits. This learning curve was secured from the work of subject No. 13; accuracy instructions were employed throughout. Part II of the practice shows a very marked irradiation curve. It should be noted that series practice in Part III brings about a marked improvement in speed without resulting loss in accuracy. The curve here shown is taken from data secured after the subject had completed a recess and a series practice, such as is shown in Part I of Fig. 2.

c. *The Irradiation Picture.*—The increase in time required for a tracing after the initial drop in the learning curve, as indicated by latter part of part I; Fig. 4, p. 14, or part II, Fig. 14, is closely paralleled by what we have styled the *irradiation picture.* This irradiation is clearly conscious to the subject, but, more important for our objective analysis, it is a matter to be observed by the experimenter; hence, it is essentially an irradiation picture.[25]. The irradiation begins with the very first circuit in part I of Fig. 4; but, one aspect of the irradiation—the increase in time required for tracing—is masked in the early part of stage I by the gain in indirect speed through straightening the course of the stylus, which it is the special function of the recess period to secure.

In the early tracings in stage I, the subject grasps the stylus much as he would a pen or pencil,—the functioning of the musculature concerned being characterized by a certain ease and facility; but, as the recess period practice is continued, the subject grasps the stylus with an observable stiffness; the staff of the stylus, which at first lay back on the hand, is now perpendicular

[25] Our conception of this irradiation, as will be shown in greater detail later, is that it is a physiological phenomenon characterized by a spread (irradiation) of nerve energy out over additional nerve fibres in the cerebrum. This becomes manifest to the experimenter as an increase in the musculature functioning in the act of tracing.

to the plane of the apparatus; the arm, which was at first mobile, now becomes stiff and rigid; the upper trunk, which at first was inclined over the apparatus, now becomes stiff and erect; the opposed musculature in the legs becomes tensed, resulting in a marked rigidity and stiffness; apparently the last musculature to be added to this assimilation is that of the unused arm. This irradiation picture continues to become more pronounced as long as the time curves continue to rise. In the latter part of stage I of Fig. 4, the irradiation picture becomes so pronounced as to be of outstanding prominence to the spectator; this being the case also during part II of Fig. 14.

This irradiation picture is quickly terminated by series practice, or slowly terminated by long repetition under recess period practice, Fig. 4. The order of elimination of this musculature is just the reverse of the order of the appropriation, i.e., the last to disappear is the opposed musculature of the used arm, which was the first synthesis to be established in the recess period practice. So long as this elimination is carried on by series practice under accuracy instructions, the opposed musculature of the used arm retains the simultaneity of function; but, when the subject traces under speed instructions, this synthesis is lost, Fig. 16, and the stroke of the stylus takes the apparent direction of the path instead of the true direction, the acquired muscular elements having been completely eliminated.

While we are not especially interested in the economy of learning in this investigation, yet, Fig. 14 points to the fact that series practice under accuracy instructions, is the economic way, without a resulting loss in accuracy, to eliminate any appropriated musculature which happens to be unnecessary for the particular degree of accuracy desired for the tracing; thus, it is true that the irradiation to the back, legs, and the unused arm may be of great value for securing a perfectly straight course down the middle of the path, without the slightest deviation; yet, such a high degree of accuracy is unnecessary, and some of the musculature could well be eliminated.

After a high degree of accuracy, one or two errors per circuit, has been attained in the irradiation curve, Fig. 14, there is no change in the smooth course of the stylus; this is shown by the

constant error curve. The same has also been shown by employing a star diagram on paper which the subject traced with a lead pencil; in this experiment, the course of the stylus is observed to remain unchanged from circuit to circuit. The changes taking place in the irradiation curve may be regarded as the addition of surplus musculature when the time curve is showing loss, and the elimination of this musculature when the time period is showing a gain. Fig. 14, part II, illustrates predominantly the function of the recess period, and part III the function of series practice.

d. *The Initial Delay.*—When the behavior before the star is reduced to its simplest elements, we shall see more clearly the part played by the recess period. In an experiment designed to simplify the response of the subject, we employed a highly trained subject to trace the diagram of our Apparatus IV under the instructions,—'Make one rapid stroke down the first side of the diagram.' This is the procedure we had adopted in a previous section in testing out the possibility of control imagery in the learning, page 40). Working under these conditions, the subject is able to make the stroke down the proper path only by delaying the movement until he has visually fixated the details of the path to be traced. This fixation requires a measurable interval of delay before the beginning of the movement, which we have called the 'initial delay.'

It should be noted that if the subject, even though he has had much experience in tracing this diagram, begins the first stroke of a series without this interval of delay, his stylus moves out on the apparent path rather than on the designated path, Fig. 9, p. 40. However, after the subject has once deliberately fixated the details of the path, he is able to make a number of strokes without the same amount of fixation, and hence with reduced initial delay, Fig. 15. The amount the subject may reduce this initial delay is largely a matter of individual difference; and depends upon the time interval between strokes. If the initial delay is reduced too rapidly, or to too low a level, the subject loses his control and his stylus moves out on the apparent side, Fig. 16.

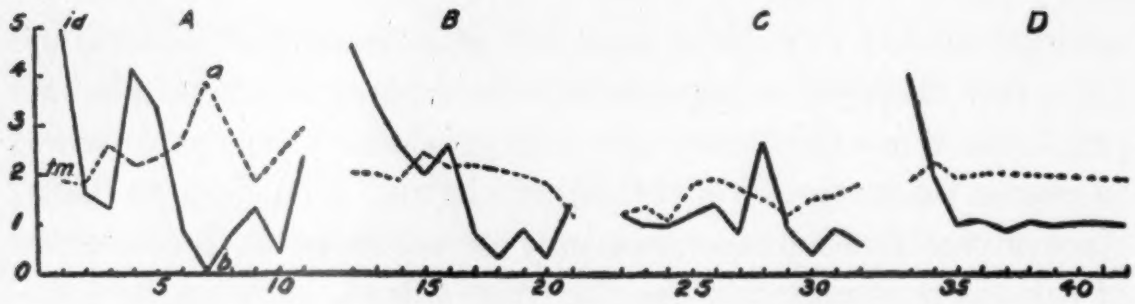

FIG. 15. A record of four experiments made with Subject No. 9 upon apparatus III. The path to be traced was the left half of the diagram as shown in Fig. 12. The instructions were: "Make the tracing with one rapid stroke." The initial delay is shown by the solid line and the time of the movement by the dashed line. The strokes were made in series and the subject selected his own time rate of making strokes. *A* and *B* were separated by a ten minute recess interval. The series *C* was made by direct vision, i.e., without the mirror; series *D*, with the mirror, was made after five days practice involving 200 strokes. The points *a* and *b* indicate a stroke which was made without any initial delay, the stylus moving in the apparent direction of the path and thus delaying the movement. The ordinate indicates time in seconds; the abscissa, successive strokes.

The points just noted are taken from results secured with a subject highly experienced in mirror tracing. From these results it is seen that the recess period works to bring about a marked initial delay which, as we have shown, involves a renewal of the long fixation of the details of the path; but, after the long fixation is made, a number of correct strokes may follow in series with greatly reduced fixation. Here it would seem that the neuro-muscular elements brought into function by the fixation, remain unchanged during a subsequent series practice; this we have called the ***perseveration of the irradiation pattern.*** It should also be noted that the recess period has little effect upon the time of the movement itself,—having its chief effect upon the initial delay or the period of visual fixation of the path to be traced.

e. *The Initial Delay and Perseveration of the Irradiation Pattern.*—From the results secured through the reduction of the behavior of the subject to the rapid tracing of one side of the star, as shown above, we are able to explain many of the points observed in our analysis of the learning curves in an earlier section.

We have observed that, after the initial drop in the learning

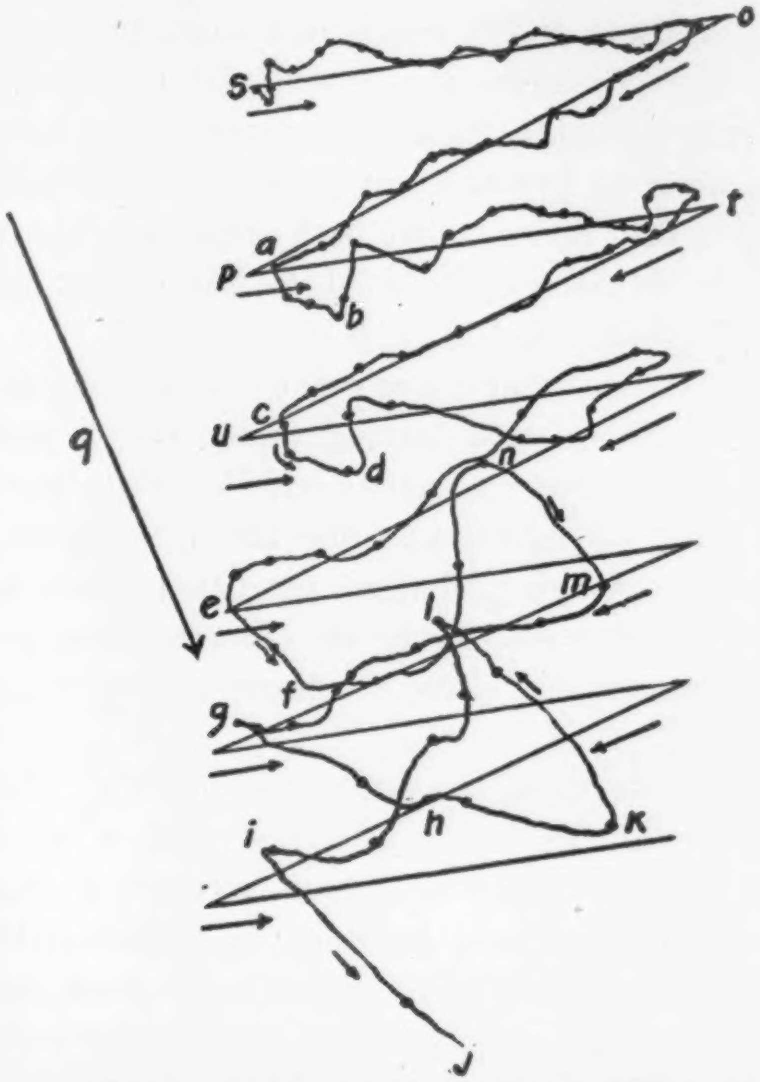

FIG. 16. An original tracing of a geometrical diagram by Subject No. 3. The tracing began at *s* and ended at *j*. The subject was asked to begin at *s* and trace the diagram as indicated by the arrows, gradually increasing his speed as he proceeded. The stations on the tracing line mark the time in fifths of a second. The control was lost in most instances on the line moving from left to right; the apparent direction of this line is indicated by the large arrow, *q*. Analysis of the tracing reveals the fact that the lines *ab, cd, ef, gh, ij, kl,* and *mn* are all parallel to the apparent direction of the line to be traced.

curve, a subject working under recess period conditions, with speed and accuracy instructions, was compelled to choose between accuracy and speed,—he could not secure both, Fig. 6, p. 16. Referring to our findings on the initial delay, we see that the recess period increases the initial delay if accuracy is secured or, in other words, if the muscular synthesis required for the accuracy is maintained. Thus, if we consider the tracing of the whole star as made up of a number of difficulties,— each involving a visual fixation of the path, a period of delay, and then

a movement,—we can see that the recess period will bring about a number of these delays which will work to increase the time of the tracing, our irradiation curve. On the other hand, series practice will eliminate these periods of delay to some extent and thus work to produce our speed of facilitation, Fig. 14. From this it may be seen that both speed and accuracy may be secured in series practice, provided the initial drop in the learning curve has been passed, Fig. 5, p.—.

It should be noted that a low rate of facilitation is obtained on continued repetition of a tracing under recess period practice conditions, Figs. 2 and 14, parts I and IV of the latter. Thus we have two types of facilitation, one through repetition in series and the other through prolonged repetition under recess period conditions. The physiological structure underlying both types is precisely the same. (See our discussion on the adequate recess).

In the later stages of the one-stroke practice, Fig. 15, it will be observed that this highly practiced subject reaches a point where the initial delay before each successive stroke becomes constant, the strokes have become rhythmical and the subject is securing just enough delay before each stroke to insure the perseveration of the irradiation pattern in the musculature of the tracing arm. Marked individual differences obtain with respect to this initial delay and rhythm of stroke among different subjects; a point that we are utilizing in a further study on the economy of learning. It is worthy of special note that this rhythm is, with some subjects, maintained over short intervals, which gives the reaction time a degree of constancy not found in earlier stages of the learning, and thus brings about a state of affairs where the short recess period has little or no effect on the initial delay. However, an unusually long recess will reestablish the long initial delay as shown in Fig. 17.[26] This state of

[26] It should be noted that tracings of the whole star by the highly practiced subject show less effect from the action of the recess period than do tracings of one side as shown in Fig. 15. This is due to the fact that the facilitation in the former is much less than in the latter. In series practice on the whole star each difficult element is repeated every ten seconds, on the average; while, in the one-stroke practice, the stroke is repeated ten times as fast.

affairs is usually called forgetting in such performances as type-writing or crossing out letters from pied type. (See discussions by Thorndike (49) where the functions of the recess are conceived solely as bringing about forgetting and eliminating fatigue).

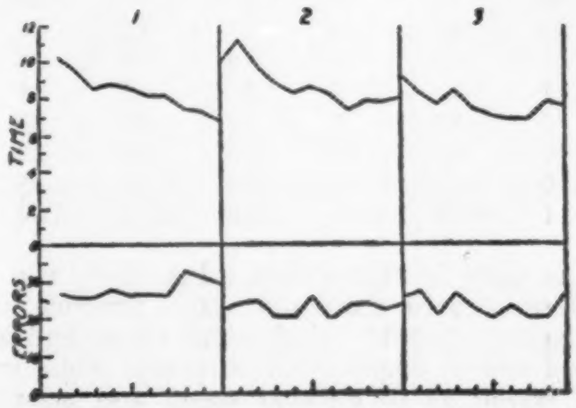

FIG. 17. This drawing presents the record of Subject No. 4 upon apparatus I after he had acquired a high rate of speed. Here are shown three groups of circuits in series; a one-week recess came between groups. It should be noted that the recess period has its greatest effect upon the speed of the tracings, due to the initial delay required in difficult places.

f. *Relation between Instructions and Type of Practice.*—Recess period practice makes possible the highest type of accuracy, and mixed series and recess period practice makes possible the highest degree of speed. A highly trained subject will have his efficiency greatly reduced if speed instructions are combined with recess period practice; or, if accuracy instrutions are combined with series practice: the highest efficiency is always secured by combining recess period practice with accuracy instructions, and series practice with speed and accuracy instructions. This state of affairs, which is another aspect of the problem we have just discussed under the initial delay, is clearly shown by Table I.

B. Physiology of the Recess Period

a. *Character of the First Movements.*—The very first movement employed by the beginner in learning to trace the star is invariably a movement in the apparent direction of the path to be traced, *AB,* Fig. 18, or, in other words, it is in the direction of the path *AC.* This first movement leads to a contact with the side of the path at *d;* at this point the stylus usually becomes

Circuit	Speed and Accuracy Instructions						Accuracy Instructions			
	Recess Period Practice				Series Pr.		Recess Pr.		Series Pr.	
	I		II		III		IV		V	
	T	E	T	E	T	E	T	E	T	E
1	15	22	21	15	22	18	30	1	30	2
2	15	20	20	10	15	7	27	2	33	4
3	15	21	19	10	21	19	32	0	35	0
4	15	12	18	12	17	16	32	1	32	0
5	12	28	22	14	20	15	32	0	30	3
6	12	20	21	15	14	12	32	0	33	3
7	13	17	20	5	16	13	31	2	30	3
8	14	19	15	15	15	10	35	1	35	1
9	13	16	15	17	15	12	30	2	30	0
10	13	16	15	15	14	12	35	1	25	2
Av.	13.7	19.1	18.6	12.8	16.9	13.4	31.6	1.0	31.3	1.8

TABLE I. In this table is shown data taken from the work of subject No. 21; the results were secured from one day's practice after the subject had acquired a high degree of skill. Under the speed and accuracy instructions, I emphasized speed and II emphasized accuracy, while in III the subject was left uninstructed except as to general speed and accuracy instructions. If we take an arithmetical average of the time and error quantities, we find that II is better than I, while III is better than either for speed and accuracy instructions. Under accuracy instructions, recess practice secures a much higher degree of accuracy than does series practice.

caught in a niche, and the subject attempts to withdraw it; these attempts in most cases serve to drive the stylus more deeply into the niche. After a number of these series attempts the stylus is withdrawn quickly in the direction of *de*, which movement is a reciprocal of the first movement, *ad*. (By a reciprocal we mean not a direct opposite of the movement *ad*, but an opposite modified by the common muscular element *AH*. It should be noted that the mirror produces no illusion with respect to tracings directly toward the right or the left; the illusion is confined entirely to those paths which run obliquely to the *AH* axis).

Following the movement *de*, we have in immediate succession the movement *ef*, which is a reciprocal of *de*, modified by the common muscular element *AH*; the movement *ef* is made up of the same muscular elements as *ad*. This series of movements serves to carry the stylus along the path to be traced. It should be observed that these are not only successive movements, but that any two successive movements involve many opposed muscular elements, that is, opposed in a physiological sense, disregarding, as before, the common muscular element *AH*.

While in the above account we have simplified to some extent

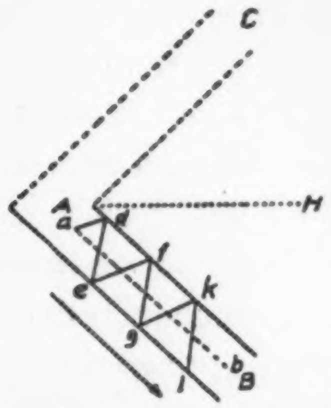

FIG. 18. A diagrammatic tracing of the first side of the star.

the type of reaction the average subject makes in his first attempts at tracing the path, yet, we have not in any sense falsified the true state of affairs. A subject may, at the outset, follow a very complicated course in tracing the first side of the star; yet, he will eventually reduce his behavior to as simple a pattern as the one we have indicated. It is also true that many subjects, even at the outset of the learning, do not produce a more complicated tracing than we have just described, Fig. 12, p. 49.

It is our finding that these successive movements which involve opposed muscular elements, are reduced by the action of the recess period, to one movement, with the muscular elements acting simultaneously. This simultaneity occurs, in the majority of cases, immediately after the recess interval; in other words, a zigzag course before the recess interval is resolved, through the interposition of the recess, into a simple, smooth course down the middle of the path.[27]

b. *Simultaneous Irradiation or Appropriation of Muscular Elements in Recess Period Practice.*—The movement down the middle of the path can be readily explained by the principle of the simultaneous functioning of neuromuscular elements which, before the recess interval, functioned successively. This simultaneous functioning has for its neurological basis a simultaneous irradiation, which is brought about by the action of the recess

[27] The reader should note that the first attempts made by the learner are in close succession, and thus are really in series. The learner brings to the situation a definite irradiation pattern—tracing by direct vision—which is not satisfactory for tracing by mirror reflection and must be disintegrated by series attempts.

interval. Here we see that the number of neuromuscular elements from the cortical center to the arm, that act simultaneously, has been increased by the effect of the recess period. It should be noted that we are presenting here a neurological conception which may be classed as a *multiple final path* conception, in contradistinction to the principle of the *final common path* of Sherrington, where many afferent fibres embouch upon a few efferent fibres, (40).[28] It is also worth noting that Pawlow (28, 55) has accounted for his conditioned reflex by the principle of irradiation; however, it does not seem that Pawlow has emphasized the simultaneous character of this irradiation.[29] This simultaneous irradiation, brought about by the recess period, is the physiological basis for one phase of neuromuscular coordination; and is, in our judgment, essential for a complete conception of the integrative functions of the nervous system, particularly, of the cerebrum. No one has seen this so clearly as Stiles in his study of the nervous system (43).[30] It is not maintained that one recess period will always bring about a complete simultaneity in the function of all of the muscular elements which have previously functioned successively; but, the recess period always works toward this simultaneity of function of opposed muscular elements.

c. *Elimination of Muscular Elements in Series Practice.*—The

[28] That Sherrington was in need of a physiological principle underlying the simultaneous functioning of opposed muscular elements, is clearly seen from his statement that the effect of strychnine in the spinal dog, which produces a simultaneity of function of opposed muscles, helps us to see how the same simultaneity might occur in voluntary movements, (op. cit. p. 106 and p. 113).

[29] This, he would not be expected to do, unless he were contrasting the simultaneous with successive irradiation, which he nowhere does. Our emphasis upon the function of the recess period entails a further refinement of terms. Pawlow, incidentally points out the necessity for time intervals between the presentations of stimuli in the establishment of the conditioned reflex; but, he does not, to the writer's knowledge, establish the recess period as a definite physiological principle underlying the irradiation.

[30] Stiles points out (p. 94) that in slow, highly controlled movements a large number of neuromuscular elements is functioning; while, in quick, rapid movements, but a few units are in function. Here, Stiles does not attempt to deal with the problem of irradiation; he is interested wholly in the number of neuromuscular elements entering into movements of various types.

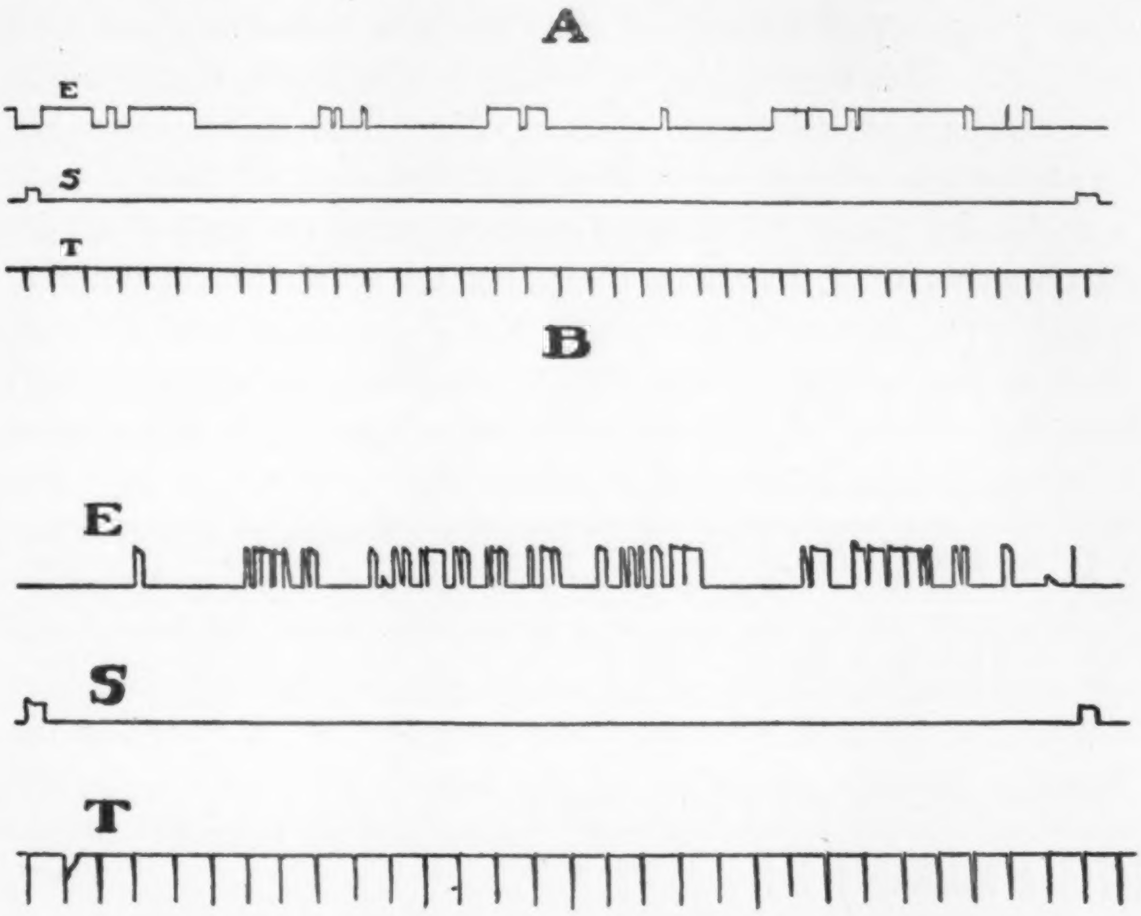

FIG. 19. An exact reproduction of two original records from the recording instrument of apparatus I. Circuit *A* was preceded by a recess interval, while *B* followed without recess. In *A* the instructions were accuracy, and in *B* speed and accuracy. Note that in *B* more errors are made; the errors are made in pairs, indicating rapid movements from one side of the path to the other and pointing clearly to the restoration of the zigzag path. The *E* line represents errors, *S* the signal for starting and stopping, and *T* the time in seconds. (Allowance should be made for the variation in the speed of the drum in the two cases).

function of series practice is to reduce the size of the irradiation pattern which has been built up by recess period practice. This reduction of the neuromuscular elements engaged in the tracing leads to marked facilitation involving rapid and easy movements. If the reduction of the irradiation pattern takes place gradually, the bilateral character of the pattern will be preserved and the subject will maintain his control. If, however, the subject be placed under speed instructions and the accuracy element disappear from his goal idea, the bilateral irradiation pattern will be completely disintegrated, Figs. 15, 16 and 19.

In the latter case, we are dealing with the problem of successive irradiation rather than with simultaneous irradiation, i.e.,

first one group of muscles receives the nervous impulse and then another. The neural energy arising in the retina is carried by the afferent nerves to the cortical center, and there passes out over first one efferent nerve fibre, and then another; thus there is a *successive* use of the opposed efferent paths,—a state of affairs in harmony with Sherrington's principles of reciprocal innervation.[31] The same loss of control, that is, a reduction of a simultaneous functioning of muscular elements to a successive or solitary functioning, also occurs when the subject is put under speed instructions and asked to trace the diagram of Fig. 9, p. 41. The first stroke that a trained subject makes when asked to make one rapid stroke down the side *AC* of this figure, is in the apparent direction, *AB,* of the path; that is, he employs again the first stroke he attempted to use when he began mirror tracing. In other words, the synthetic neuromuscular complex *AC,* acquired in the learning through the effect of the recess, has been completely eliminated as a result of the instructions, and we have left simply the *AB* element.

We modified our experiment so as to throw light upon the effect of alcohol upon the coordinations in a highly trained subject. From these experiments, Fig. 20, we are able to draw the significant fact that the alcohol tends to transform the simultaneous functioning of the opposed muscular elements into a successive functioning of these elements. In other words, the subject who has acquired the smooth course of the stylus down the middle of the path is, through the effect of alcohol, reduced to a stage where the zigzag path returns and his accuracy or control is lost. Our experiment shows that there is a slight loss in speed and a marked loss in accuracy, due to the effect of the alcohol; the total effect of the alcohol is the same as results from speed instructions.

[31] It is to be borne in mind that Sherrington worked chiefly on the spinal dog and, as a result, his principle of the final common path and reciprocal innervation applies mainly to the spinal centers; however, he does not apply this principle to cerebral functioning. In fact, one gathers from a careful study of Sherrington that he considers this principle of the final common path one of the fundamental principles of nerve integration—a fact not in harmony with our findings.

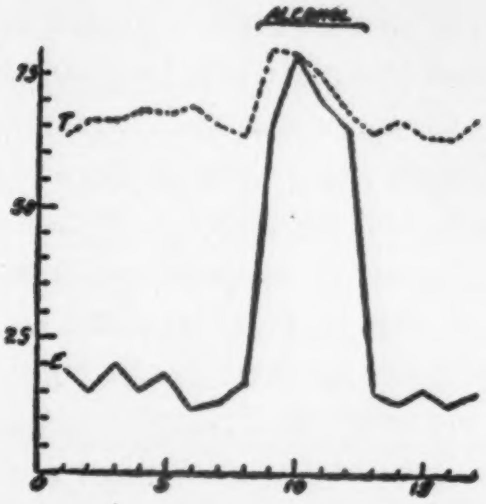

FIG. 20. An experiment showing the effect of alcohol, performed upon Subject No. 18. This subject had reached a level of efficiency which varied only slightly from day to day. Each station in the curves represents an average of five circuits in series; the series were separated by recess intervals of five minutes. In a previous experiment a much smaller amount of alcohol was used and the results indicated a small loss in accuracy and a slight gain in speed.

d. *Later Stages of Irradiation.*—By referring to Fig. 15, it will be observed that the irradiation produced by the recess period becomes less and less as series practice is inserted into the practice; which means that, in time, very little irradiation will be shown in the learning curve. This irradiation may be restored by the insertion of a very long recess interval, as in Fig. 17, where a high rate of speed obtains.

Inasmuch as, in the earlier stages of the learning, we get such a high rate of disintegration from series practice, Fig. 2, p. 13, and such a marked integration from recess period practice, it might be assumed that the subject acquires an immunity to these forces of integration and disintegration as practice continues. This is true simply because the learner faces a different situation in the two cases. In the early stages of practice the learner does not have the appropriate movement and, as a result, he fixates visually the same point on the star many times in close succession. We have the record of one subject who repeated the same movement (tracing in the apparent direction) forty-seven times in tracing the first side of the star. In later stages of practice, when the subject has acquired the mirror tracing coordination, the same point on the star is visually fixated only once in every ten seconds, on the average.

This state of affairs is also clearly shown when we take any highly practiced learner and place him in our one-fast-stroke practice, Fig. 15. His rate of neural disintegration or loss of control will be seen to depend upon three factors: (1) an individual difference factor, dependent upon bodily metabolism, (2) state of health, which shows considerable variation from day to day, (3) temporal frequency of the strokes, in other words, the speed of stroke and the initial delay allowed by the conditions of practice. If allowed to select his own conditions each learner will adopt a rhythm suited to his own rate of anabolism and katobolism.

e. *The Adequate Recess Interval.*—While we have found throughout our experiment that the recess interval is the sole factor which brings about the necessary simultaneity in neuromuscular functioning; yet, it has been extremely difficult to measure, on all occasions, the precise length of interval required for such a physiological state. This is due to the fact that individual differences obtain here in a very marked degree; some subjects may acquire the simultaneous irridation necessary for the early stage of the learning, through the insertion of rather short recess intervals; yet, others may require, for adequate irradiation, time intervals which are considerably longer and more frequent. We have found, for example, in our experimentation, that some subjects will have the zigzag path resolved into a smooth path by recess intervals as short as ten seconds, while others evidently require recess intervals which are considerably longer. We have not observed a case of simultaneous irradiation in the very early stage of learning after a recess interval shorter than ten seconds.

There is much evidence that the adequate recess interval varies greatly from time to time in the same individual, depending, perhaps, upon his general metabolic condition. From our experiments involving recess periods of a few seconds and others of varying lengths up to one year, we are able to derive the law that the major part of the structural changes underlying the simultaneous irradiation,[32] brought about by the recess interval, takes place

[32] That these changes are metabolic and have to do with the anabolic processes of restoring the cerebral cell to the condition existing before stimula-

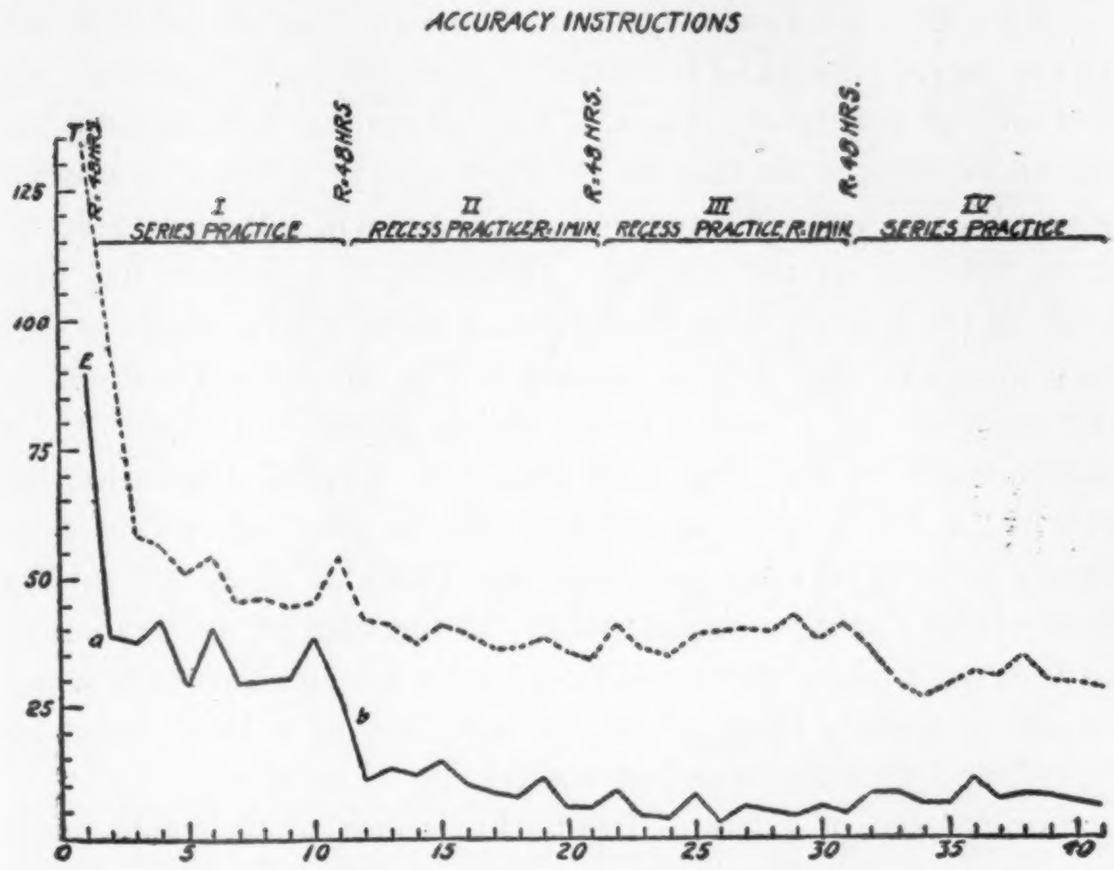

FIG. 21. A curve made from the average of three subjects who show a gain in accuracy in early series practice. A comparison between this curve and that in Fig. 2 reveals the fact that the subjects in the latter group were affected more by the recess periods than the former. These three subjects were the only ones in a class of thirty students to show improvement in accuracy in early series practice. See Table II, *B*.

in the earlier part of the interval. There are some evidences to indicate that the curve for these changes, secured through average results of a group, will parallel closely that found by Ebbinghaus (11) in his curve of forgetting, and in particular the curve found by Finkenbinder (12) in his analysis of the process of forgetting.[33]

tion, we have no doubt. Matthews has pointed out (Physiological Chemistry, Wm. Wood Co., 1916, Chap. XIII) that in the brain, we have all the necessary provisions made for the most intense and most rapid metabolism to be found in the entire body. Our results show that some subjects, reduced to a condition in the early stages of practice where improvement is not possible, will recover within ten seconds.

[33] At the present time an investigation is in progress at the University of Utah which aims to determine the exact length of recess interval required for different learners at various stages of the learning. In this investigation we are employing the rate of assimilation of muscular elements, brought about

There are numerous evidences to indicate that the effect of the recess period is relative and depends upon the type of practice the learner has undergone. Thus, if the learner has been making one circuit of the star per day for twenty-five days, a recess of a week, a month, or even nine months, (Fig. 7), will not noticeably reduce the time of the tracing. However, if a subject has been making ten circuits in series per day, and has thus acquired a high rate of speed, the speed of tracing will be very much reduced by the insertion of a week's recess in his practice, (Fig. 17). It would seem in the first case that the cortical irradiation has reached a stable form or pattern, due to the twenty-four hour recess periods between practices, and probably does not enlarge appreciably during a recess; while, in the case of an irradiation pattern built up by series practice, we have a small pattern which would be greatly enlarged by the insertion of a long recess interval, and thus the speed of the tracing is reduced.

The pattern of bilateral irradiation seems to be stable under conditions of one circuit per day practice, which is shown by the fact that an arithmetical average of the time and error quantities will be approximately constant, (later stages of the learning in Figs. 4 and 6). Our quantitative results show that if circuits are multiplied oftener than once per day the above constant does not occur, and the improvement continues to take place, at a logarithmic rate, throughout practice, Figs. 5 and 7. For purposes of clearness, we have called all improvement in time of tracing, taking place from the reduction of an irradiation curve by means of practice with twenty-four hour recess periods, Fig. 3, Part I, *primary facilitation;* while that gain in speed of tracing brought about by series practice, or with recess periods of less than twenty-four hours, is *secondary facilitation.* Primary facilitation is thus seen to be limited by the speed of functioning of a stable irradiation pattern, built up by twenty-four recess periods; secondary facilitation is unlimited, except physiologically.

We have been frequently amazed at the entire absence of

by recess periods of varying length, and the rate of dissimilation, brought about by series practice. While the problem presents numerous difficulties, it does not seem impossible of solution.

forgetting in this problem. In a number of instances, (Figs. 4, 5 and 7), recess intervals as long as eight months in length occurred in the learning without any visible sign of forgetting as a result. The explanation for this seems, to the writer, to lie in the fact that the coordinations acquired in this act of learning are related to the elements of a situation—mirrorwise perception—not found in the case of other acquired coordinations. If the subject lived in a mirrorwise world, there would then be forgetting in mirror tracing, since the coordinations acquired for similar situations would become fused and thus produce a definite loss through interference,—the chief factor in motor forgetting. It is worthy of note that the absence of forgetting in our problem has contributed much to our findings relative to the positive value of the recess period.

f. *Behavior of the Eye under Various Conditions.*—We have already indicated in our introspective analysis that during recess period practice under accuracy instructions, the visual attention of the subject is directed to the details of the path to be traced by the stylus; this visual attention assumes the character of fixation. In series practice, or in practice under speed instructions, the visual attention of the subject was found to lose this fixation character and to become distributed over a larger and larger area of the star as practice proceeds. In this case the details of the path to be traced are not observed; the subject reacts to his visual impression of the general direction of the path.

It is now only necessary to observe that when the visual attention is narrowed down to details, during recess period practice, the neuromuscular elements from the cortical center to the arm, are functioning simultaneously; but when the visual attention is too much spread out, so as to perceive only the general direction of the path, the neuromuscular elements function, not simultaneously, but successively, or in solitary fashion. From this, we gather that the control in this problem is correlated with the behavior of the eye; and the analytical or obtuse receptor functions of the eye depend upon the conditions of practice,—series or recess period. Woodworth (54) found much the same state of affairs in his study of the accuracy of voluntary movements; although

he does not carry the analysis so far as we have attempted in this investigation.

It is well to note at this point that our subjects in the alcohol experiment reported that the drug seemed to affect the eye in a very noticeable way, and, as a result, they were not able to visually fixate the details of the path. The tracings secured under the effect of alcohol show a definite loss in accuracy.

From the foregoing findings it is apparent that when the eye acts as an analytical receptor,—visual attention directed to details of the path,—we have simultaneous irradiation over the efferent neuromuscular paths; but when it acts as an obtuse receptor,—as in the perception of the general trend of the path,—we have successive irradiation, describable in terms of reciprocal innervation.

g. *The Work of Pawlow, Sherrington, and Others, in Relation to our Findings.*—Pawlow has explained the conditioned reflex by the principle of irradiation (29). He has also observed (32) that this irradiation or conditioning takes place only when the stimuli are separated by time intervals. From this it seems that the Pawlow conception of the conditioned reflex and our own findings as to the physiological foundations of the learning in this investigation are in perfect harmony.

A somewhat clearer insight into the relation between Pawlow's work and our own findings, however, is secured by a further analysis of his experiments. He succeeds in conditioning a new stimulus when that stimulus is applied intermittently, but simultaneously with or in close succession to the functioning of the unconditioned response. Thus, the meat-powder stimulus applied to the tongue is simultaneous with the ringing of the bell; and, after a number of repetitions of this combination, the sound of the bell is observed to stimulate the secretion of the saliva, which was formerly brought about only by the unconditioned, meat stimulus. There is then an irradiation from the auditory, affervent nerves to the salivary, efferent nerve fibres.

The relation of this principle of irradiation to our own problem will probably be yet more apparent, if it is assumed that the auditory stimulus originally produced an *unconditioned* response, such as the perking of the ears of the dog. Then it will be seen that, after the conditioning, the auditory stimulus flows out over, not only the effervent paths which produced the perking of the ears, but also the salivary efferent paths which were in simultaneous function with the perking of the ears.

Pawlow and his pupils have also shown (30, 38, 52) that the

conditioned reflexes are worn out by repetition without adequate recess intervals. When these conditioned reflexes are not completely worn out, they are partly restored by the action of the recess period. These investigations have also shown that the conditioning of an unnatural stimulus is always brought about by what they call an "analytical receptor"; in other words, the irradiation is produced by such a receptor.

The keystone in the arch of Sherrington's system is the final common path, which is, neurologically, just the opposite of our principle of the multiple final path in simultaneous irradiation. Sherrington's principle of the final common path has been deduced largely from his work upon the spinal dog, where his experiments have involved only the obtuse receptors below the medulla; thus, as it appears to us, his principle of the final common path is directly dependent upon the type of reaction secured through stimulation of the *obtuse* touch, or pain, receptors on the surface of the dog's body. The work of Sherrington needs, in our judgment, to be supplemented by the work of Pawlow, if we would have a physiology of the nervous system upon which human learning, even of the trial and error type, may rest. The work of Pawlow may be clarified by the findings of this investigation,—that one aspect of the learning, simultaneous irradiation, is brought about directly by the effect of the recess period which produces the analytical function of the analytical receptors. The work of Pawlow in pointing out the function of the analytical receptors, the foundation of the irradiation, is then seen to be supplemented by our finding that the eye may function as an analytical, or as an obtuse, receptor; and the manner of presenting the stimulus, in series or intermittently, determines the character of this function.

Our contention is that Sherrington's final common path conception is fairly adequate as an explanatory principle for certain nervous integrations of the spinal dog, where the irradiation is largely to closely allied musculature—immediate spinal induction in Sherrington's nomenclature; but it is far from adequate for the human subject or, even for the dog, with analytical receptors and cerebrum intact.

Our criticism of Sherrington's physiological system, that it is wholly inadequate to furnish a physiological foundation for human learning, leads us to a similar criticism of the system employed by Thorndike (49, 50) in his psychology of learning. Thorndike advances a semi-behavioristic system with but one physiological element,—repetition of the stimulus. He attempts to build a system about this one element by proposing his conception of "bonds" or "connections," functional terms indicating a state of affairs that requires some dynamic agency to bring about their existence; repetition alone cannot establish his connections. The dynamic element needed for this system is found in the "feeling of satisfyingness," which has, as its physiological foundation, the conduction of neurones ready to conduct,—a principle as vague as it is unphysiological. Without further necessary details regarding the structure of this "readiness of neurones to conduct," physiologists must certainly regard this state of affairs as interpretative and not a scientific description of an observable situation. Thorndike's predicament is not improved, for physiology, by invoking the aid of the psychological aspect of this readiness of the neurones to conduct, viz., the "feeling of satisfyingness," which occurs when neurones ready to conduct, do conduct, (50).

In our opinion the term bond, or connection, is an artifact, wholly unsupported by analysis, which is made to appear workable by a vague, as well as an unwarranted, assumption that the bond or connection is established, or "stamped in," by the feeling of satisfyingness following upon a chance establishment of the bond. Either the readiness to conduct or the satisfyingness is without physiological foundation. Science, clearly, must require an element, other than the repetition of a stimulus, in a physiological system that would explain human learning.[34]

Book, in his study of typewriting (4) points out that the purposeful use of a new habit seemed to be more of a hindrance than a help. He also holds (p. 171) that in later stages of the learning, the writing becomes harder and harder to attend to. This is

[34] We are in agreement with Titchener (51) that, in the last analysis, psychological processes are explained by the underlying physiological processes.

in agreement with our contention that as practice proceeds, the visual attention spreads over a larger and larger field, and thus becomes more general; the details drop out.

Book holds that improvement after recess is due to the fact that during the recess period certain 'psychophysical difficulties' and 'interfering tendencies' drop out. On further analysis one finds that the interfering tendencies which he has in mind are made up, at least in part, of the ever present tendency of the subject to attempt speed before the co-ordinations are ready. In support of this fact, Book holds (p. 179) that the vital problem in learning is determining just how fast to push ahead. Now, it is the recess period, as has been shown in this investigation, which corrects this tendency to push ahead too fast and brings the individual back to a stage when his attention is devoted to the details. Book points out also (p. 179) that the learner can do nothing to control his fluctuations of attention; "it is not what the learner would like to do, but what his mental and physical conditions will let him do." This is in substantial agreement with the results obtained in this investigation.

We find also that our findings are supported by many of Woodworth's results in his study of the accuracy of voluntary movement (54). Throughout his study he contends that visual control works for accuracy unless the movement be at high speed; "at high speeds the accuracy contributed by voluntary attention, using either eyes or muscular sense, amounts to zero; by decreasing the speed we greatly increase the accuracy due to visual control." This is in agreement with the position taken in this investigation on the relation of visual control to speed.

Woodworth points out (p. 39) that "if we distinguish between initial adjustment and current control, we see that the conditions of current control are not changed by altering the time interval between strokes; a long interval works slowly on the initial adjustment." He finds, further, (p. 74) that when the speed of a movement, as in handwriting, is slow enough 'to permit fine secondary adjustments' the eyes assist greatly in securing accuracy; when the eyes are not used, however, he finds that "extreme slowness is a disadvantage; higher speed of writing move-

ment is secured with eyes closed than with eyes open." This is in complete agreement with the findings in this investigation that the visual perception when concentrated leads to accuracy.

Many other investigators, such as Binet (2), Pechstein (33) and Lashley (24) have found experimental confirmation of the value of the recess period. Finally, we should note that James (18) made famous the observation that "we learn to skate in summer and swim in winter," which, more than any other observation, has stimulated this investigation.

IV. SUMMARY

In this study of trial and error learning, we have made an analysis of the behavior of human subjects under definite instructions and before a constant situation,—namely the tracing of a simple diagram by mirror reflection. The study has revealed at every point the behavioristic nature of this type of learning; it has shown that learning to trace, by mirror reflection, a line which runs obliquely to the median plane of the body, consists entirely in acquiring a modification of the response the subject brings to the situation as a beginner. A description of the progressive modification of this response, under such conditions as varied instructions to the learner, varied temporal distribution of practice periods, constitutes the material of this paper.

We have observed the repetition of the response of the learner with and without recess periods between the repetitions, and our findings here are to the effect that the recess period, in early stages of the learning, makes possible the attainment of accuracy; and that repetitions without recess, in later stages of the learning, make possible the attainment of speed. Accuracy was shown to depend upon the simultaneous functioning of certain opposed muscles—simultaneous irradiation—predominantly of the used arm; speed was seen to depend upon two closely related factors, —namely, elimination of unnecessary musculature and elimination of the period of delay required and made possible by recess period practice when the eye is fixated narrowly upon the details of the tracing; these two elements, in our interpretation, constitute physiological facilitation.

In accuracy tracings the eye was shown to act as an analytical receptor, being fixated upon the details of the tracing; in speed practice the visual perception is spread out over a large area of the objective situation. When the eye is acting as an analytical receptor, simultaneous irradiation obtains in the efferent neuromusculature of the body parts concerned in the tracing. When the eye begins to act as an obtuse receptor, the functioning effer-

ent neuromusculature becomes reduced and, as a last stage of this, when great speed has been attained, the efferent neuromusculature functions according to the principle of reciprocal innervation, that is, only closely allied neuromuscular elements are innervated and the opposed elements are inhibited.

The value of instructions given to a learner was found to depend wholly upon the physiological conditions resulting from the type of practice—series or recess period—under which the learner is working; recess period practice making accuracy possible, and series practice, speed.

It was shown that the mental image of a movement in mirror tracing cannot control the movement. The feeling of pleasantness following a satisfactory movement was shown to have no effect upon the reappearance of the movement; and this feeling of pleasantness was shown to have no place as an element in bringing about the improvement at any stage of the learning.

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TABLE II. (folded insert opposite). This table shows the quantitative data from the work of thirteen students, all working under identical conditions as to instructions to subjects and conditions of practice. The exact length of the recess intervals is shown in Figs. 2 and 21, which were plotted from the averages shown in *A* and *B* of the table. The headings at the top indicate the conditions of practice maintained thoroughout the experiment.

Part *A* of the table represents the work of ten students who did not show improvement in accuracy in the early part of the learning during ten circuits of no recess practice. Part *B* represents the work of three students who did show a slight improvement in accuracy during this practice; here, however, the improvement is so slight as to be almost negligible when compared with such improvement as takes place in early recess period practice, Figs. 4, 5, 6 and 7. It will be observed that the subjects in Part *B* are everywhere less affected by the recess periods than are the students in Part *A*.

Table II

		Practice	Recess		No Recess													
		Circuit	1	2	3	4	5	6	7	8	9	10	11	12	13	14	1
A	TIME	Number of Subject 1	70	33	44	30	28	30	30	32	23	30	33	52	55	45	
		2	71	61	55	59	49	45	37	42	42	37	38	49	35	37	
		3	88	55	55	45	60	47	38	51	31	31	37	51	39	32	
		4	134	42	34	26	68	36	103	33	36	47	37	68	68	62	
		5	180	43	32	35	32	30	34	27	22	26	39	101	87	67	
		6	30	21	32	35	25	33	26	28	33	36	21	34	36	34	
		7	121	27	28	25	31	27	25	35	38	40	40	104	63	75	
		8	184	68	64	83	71	56	48	46	43	42	49	88	83	67	
		9	171	90	50	61	47	55	69	48	63	72	37	61	43	43	
		10	120	36	64	43	47	41	38	43	52	59	44	44	26	31	
		Total T	1169	476	458	442	458	400	448	385	383	420	375	652	535	493	5
		Average	116.9	47.6	45.8	44.2	45.8	40.0	44.8	38.5	38.3	42.0	37.5	65.2	53.5	49.3	5
	ERRORS	Number of Subject 1	11	26	13	8	21	11	11	18	10	22	21	1	0	0	
		2	53	35	46	54	41	59	39	35	33	31	37	24	15	17	
		3	13	7	14	9	27	15	17	10	10	4	11	5	2	1	
		4	12	2	4	3	25	16	36	13	15	6	8	0	0	0	
		5	157	58	45	60	50	58	45	43	34	35	65	11	8	4	
		6	58	31	64	55	57	57	40	51	47	62	40	15	26	19	
		7	170	45	45	45	48	28	22	41	40	44	60	14	3	9	
		8	10	4	3	17	10	9	16	7	10	9	14	1	0	0	
		9	95	58	57	67	64	74	92	62	88	81	62	7	18	10	
		10	13	28	24	6	21	10	23	16	12	24	25	9	11	7	
		Total E	592	294	325	424	364	437	336	296	299	308	443	87	83	67	
		Average	59.2	29.4	32.5	42.4	36.4	43.7	33.6	29.6	29.9	30.8	44.3	8.7	8.3	6.7	2
B	TIME	Subject 11	128	85	56	49	45	57	38	38	37	38	40	53	43	37	
		12	205	165	100	90	91	82	76	67	67	67	97	53	55	47	
		13	70	40	18	28	20	25	24	34	31	31	27	20	23	29	
		Total T	403	290	174	167	156	164	138	139	135	136	164	126	121	113	1
		Average	134	96.6	58.0	55.6	52.0	54.6	46.0	46.3	45.0	45.3	54.6	42.0	40.3	37.6	4
	Errors	Subject 11	137	43	38	38	25	50	34	18	35	33	25	4	7	8	
		12	24	10	32	7	7	14	4	6	2	7	1	1	2	0	
		13	109	63	43	81	54	57	46	62	51	74	56	28	32	28	
		Total E	270	116	113	126	86	121	84	86	88	114	82	33	41	36	
		Average	90.0	38.6	37.6	42.0	28.6	40.3	28.0	28.6	29.3	38.0	27.3	11.0	13.6	12.0	14

o Recess					Recess Period										Recess				
7	8	9	10	11	12	13	14	15	16	17	18	19	20	21	22	23	24	25	26
30	32	23	30	33	52	55	45	37	31	28	33	33	37	33	37	31	34	28	30
37	42	42	37	38	49	35	37	50	52	55	65	75	67	68	67	71	83	80	64
38	51	31	31	37	51	39	32	33	32	34	28	20	24	25	34	32	30	22	25
103	33	36	47	37	68	68	62	61	61	60	66	68	64	65	65	57	57	55	47
34	27	22	26	39	101	87	67	62	63	64	71	77	78	71	72	60	59	66	62
26	28	33	36	21	34	36	34	41	41	43	46	43	44	42	48	49	42	40	41
25	35	38	40	40	104	63	75	90	96	91	90	78	71	62	62	52	45	45	40
48	46	43	42	49	88	83	67	70	71	64	54	53	49	43	60	60	60	51	48
69	48	63	72	37	61	43	43	33	31	32	29	34	35	33	40	37	34	30	34
38	43	52	59	44	44	26	31	31	32	34	33	44	45	34	36	25	30	21	21
448	385	383	420	375	652	535	493	508	510	505	515	525	514	476	521	474	474	438	412
44.8	38.5	38.3	42.0	37.5	65.2	53.5	49.3	50.8	51.0	50.5	51.5	52.5	51.4	47.6	52.1	47.4	47.4	43.8	41.2
11	18	10	22	21	1	0	0	0	0	1	0	2	0	1	0	0	0	2	0
39	35	33	31	37	24	15	17	8	10	7	9	7	3	6	2	4	2	1	2
17	10	10	4	11	5	2	1	4	3	0	0	3	3	2	6	1	2	2	0
36	13	15	6	8	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
45	43	34	35	65	11	8	4	5	4	9	0	3	1	5	10	7	3	0	6
40	51	47	62	40	15	26	19	25	23	27	18	11	14	20	8	14	9	11	14
22	41	40	44	60	14	3	9	8	9	11	6	2	4	2	11	6	7	3	2
16	7	10	9	14	1	0	0	0	3	1	1	0	0	0	0	0	0	0	1
92	62	88	81	62	7	18	10	10	3	11	7	7	17	6	5	12	7	6	10
23	16	12	24	25	9	11	7	11	3	5	5	4	2	6	1	3	5	1	2
336	296	299	308	443	87	83	67	71	68	72	46	39	44	48	43	47	35	26	37
33.6	29.6	29.9	30.8	44.3	8.7	8.3	6.7	7.1	6.8	7.2	4.6	3.9	4.4	4.8	4.3	4.7	3.5	2.6	3.7
38	38	37	38	40	53	43	37	46	44	38	34	40	38	35	26	23	23	26	29
76	67	67	67	97	53	55	47	43	43	40	40	42	40	40	42	41	38	38	38
24	34	31	31	27	20	23	29	32	30	31	34	31	27	25	53	42	42	50	48
138	139	135	136	164	126	121	113	121	117	109	108	113	105	100	121	106	103	114	115
46.0	46.3	45.0	45.3	54.6	42.0	40.3	37.6	40.3	39.0	36.3	36.0	37.6	35.0	33.3	40.3	35.3	34.3	38.0	38.3
34	18	35	33	25	4	7	8	10	4	0	5	7	2	0	10	4	3	7	0
4	6	2	7	1	1	2	0	0	1	2	2	2	0	0	5	1	1	2	2
46	62	51	74	56	28	32	28	34	25	22	16	27	16	16	14	9	7	15	6
84	86	88	114	82	33	41	36	44	30	24	23	36	18	16	29	14	11	24	8
28.0	28.6	29.3	38.0	27.3	11.0	13.6	12.0	14.6	10.0	8.0	7.6	12.0	6.0	5.3	9.6	4.6	3.6	8.0	2.6

Recess Period						No Recess								
26	27	28	29	30	31	32	33	34	35	36	37	38	39	40
30	31	31	27	25	23	38	34	38	39	38	40	34	35	38
64	65	68	67	60	60	51	65	68	57	61	72	60	40	52
25	16	19	26	23	24	18	18	22	23	18	18	21	18	19
47	46	49	54	60	61	47	50	50	53	49	48	44	42	37
62	59	58	54	50	60	49	41	47	45	42	35	35	30	33
41	47	40	39	37	40	38	39	36	35	34	33	35	31	31
40	35	35	38	39	36	41	32	29	31	33	31	31	29	29
48	53	46	45	46	40	50	45	45	40	37	39	42	40	35
34	32	33	30	28	29	25	26	32	27	28	29	29	26	25
21	22	16	15	20	22	25	31	35	40	27	26	29	35	33
412	406	394	395	388	395	382	381	402	390	367	371	360	326	332
41.2	40.6	39.4	39.5	38.8	39.5	38.2	38.1	40.2	39.0	36.7	37.1	36.0	32.6	33.2
0	1	0	1	1	3	0	0	0	0	0	0	0	0	1
2	4	2	0	0	2	3	5	3	3	0	2	3	4	3
0	5	5	1	0	0	4	2	4	0	0	3	0	2	2
0	0	0	0	0	0	0	0	0	0	0	0	2	1	0
6	1	2	3	2	0	7	5	5	11	13	4	5	6	14
14	8	2	7	6	6	14	7	6	9	8	5	7	5	9
2	4	1	3	6	1	7	6	5	10	8	8	6	1	4
1	1	0	0	2	0	4	0	0	0	2	1	2	0	0
10	5	7	7	4	8	6	0	9	3	9	3	1	1	6
2	0	8	5	9	2	8	4	11	0	6	2	7	4	5
37	29	27	27	30	22	53	29	43	36	46	28	33	24	44
3.7	2.9	2.7	2.7	3.0	2.2	5.3	2.9	4.3	3.6	4.6	2.8	3.3	2.4	4.4
29	31	26	31	32	34	28	25	26	26	27	22	24	26	22
38	40	41	44	39	40	42	33	27	35	38	42	54	39	40
48	45	47	53	52	48	38	31	27	25	28	27	27	25	27
115	116	114	128	113	122	108	89	80	86	93	91	105	90	89
38.3	38.6	38.0	42.6	37.3	40.6	36.0	29.6	26.6	28.6	31.0	30.3	35.0	30.0	29.6
0	5	7	2	10	9	15	10	13	4	11	9	13	8	7
2	1	2	0	3	5	5	7	4	5	6	4	1	4	2
6	12	6	11	5	0	4	8	2	9	18	7	10	11	10
8	18	15	13	18	14	24	25	19	18	35	20	24	23	19
2.6	6.0	5.0	4.3	6.0	4.6	8.0	8.3	6.3	6.0	11.6	6.6	8.0	7.6	6.3